Appendix D. Soils, Hydrology, and Water Quality Technical Appendix

Appendix D. Soils, Hydrology, and Water Quality Technical Appendix

This section describes the soil properties that are relevant to biosolids application; mobility, bioavailability, and potential toxicity of biosolids; and general soil characteristics in each of the nine Regional Water Quality Control Board (RWQCB) regions. In addition, this section describes hydrologic and water quality issues related to biosolids application. The fate and transport characteristics of pathogens and radioactive substances related to biosolids application are described in Chapter 5, "Public Health".

Environmental Setting for Soils

Summary of Soil Properties Relevant to Biosolids Application

The soil properties described below affect the suitability of a site to be used for biosolids application. Some of these properties may change as a result of biosolids application. Additionally, most of the properties are closely related to the productivity of a site for food and fiber crop production and livestock forage.

Texture

Probably the most significant soil property relative to biosolids application is texture (i.e., the proportions of sand-, silt-, and clay-sized particles). With other factors held constant, fine-textured soils (e.g., silty clays and clays) tend to have relatively high capacity to retain nutrients and metals, have moderate water-holding capacity (i.e., the amount of water that can be taken up by plant roots [measured as inches of water per inch of soil] or that is available throughout the root zone), have slow infiltration capacity and permeability (to water and gas movement), and be relatively difficult to till. The pH (discussed below) of fine-textured soils ranges from near neutral to alkaline. Most clayey soils are fairly resistant to erosion when the vegetation cover is removed, except on steeper slopes.

Coarse-textured soils (e.g., loamy sands) tend to have relatively low nutrient- and water-holding capacities, have low native fertility, have rapid infiltration capacity and permeability, and be easily tillable. Many coarse-textured soils have low organic matter content. The pH of coarse-textured soils ranges from near neutral to acidic. Sandy soils are among the soils most subject to water erosion and high percolation rates.

Medium-textured soils (e.g., loams and silt loams) generally have fertility and hydrologic characteristics intermediate between fine- and coarse-textured soils, except that they have the highest available water-holding capacity. Medium-textured soils, particularly those with high organic matter content, are generally resistant to erosion on gentle to moderate slopes.

Cation Exchange Capacity

Cation exchange capacity (CEC) is a measure of a soil's net negative charge and a measure of a soil's capacity to retain and release cations (i.e., positively charged ions) for uptake by plant roots. Cations (e.g., calcium and ammonium) can be essential for plant growth in small concentrations but may be toxic in larger concentrations (e.g., molybdenum, zinc, and copper). Some trace elements, such as lead, are not required in any amount but may be toxic to plants and the animals that feed on them. The level of CEC is controlled primarily by the amount and type of clay mineral in the soil and the content of humus (highly decomposed organic matter) in the soil. In coarse-textured soils, humus may provide most of the soil's CEC. For a given quantity (i.e., weight) of soil, the CEC of humus is typically several times that of most pure clays. Clayey soil commonly has a CEC more than fives times that of sandy soil. A high CEC is desirable in soil because it lessens or prevents essential nutrient loss from the soil by leaching (Donahue et al. 1983). Soils with high CEC can also immobilize heavy metals such as copper and lead by binding the negatively charged metal anions to cation exchange sites associated with the clay minerals and organic matter.

Organic Matter

Organic matter, another important property of soil, enhances the physical condition of surface soil layers by binding together individual soil particles into larger aggregates, which give structure to the soil. Organic matter especially benefits the structure of sandy soils. Improved soil structure creates large pores through which gases and water can move and roots can penetrate. Accordingly, soils with good structure tend to have a lower bulk density and be more permeable than soils with poor structure. A well-aerated, permeable soil is usually more productive than a poorly aerated soil. High permeability tends to improve a soil's infiltration capacity and make the soil easier to till (Donahue et al. 1983). Further, soils with large, stable aggregates (i.e., well-structured soils) are more resistant to erosion than soils with poor structure (National Academy of Sciences 1996). Organic matter also improves tillability (particularly among coarse- and fine-textured soils) by promoting good structure of surface layers (Donahue et al. 1983).

Soil organic matter content also affects the capacity of the soil to retain water and many soluble nutrients and metals, particularly in coarse-textured soils. Organic matter is also the source of most of the nitrogen in an unfertilized soil and can be an appreciable source of phosphorus and sulfur. Soil microbes use organic matter as a food source (Donahue et al. 1983).

pH

Soil pH is a measure of the acidity or alkalinity of a soil. Nearly all California soils have a pH ranging from 5.0 to 8.5; a pH of 7.0 is considered neutral. A low pH (e.g., an acidic soil with a pH of 5.5) suggests that soil nutrient concentrations and microbial activity are low (Tucker et al. 1987). Bacteria that decompose organic matter and therefore release nitrogen and other nutrients for plant growth are less active in strongly acidic soils. In strongly acidic soils, most heavy metals and some nutrients are soluble and aluminum and manganese may be present in toxic concentrations. A high pH (e.g., an alkaline soil with a pH of 8.0) suggests that concentrations of some soil nutrients (particularly calcium and magnesium) are high; some soils with high pH have high concentrations of soluble salts, which can limit plant growth and affect the type of crops that can be grown on a site (Donahue et al. 1983). High pH levels can also bind soluble phosphorus, making it unavailable for plant growth. Iron (and, to a lesser degree, zinc) may be insufficient to allow sensitive crop species to grow in high-pH, calcareous soils (Tucker et al. 1987). Soil pH also greatly affects the solubility of minerals and many heavy metals, and therefore affects their availability for plant growth and uptake in biomass and their potential to be leached from the soil profile. A slightly acidic condition (e.g., pH 6.5) is best for many agricultural crops because overall, macronutrients and micronutrients are most available for plant uptake under slightly acidic conditions (Donahue et al. 1983). Maintaining neutral to slightly alkaline conditions is often recommended for soils if high levels of heavy metals are a concern because the metals tend to be less mobile at these pH conditions.

Salinity

Salinity refers to the salt content of soil. Salts are dissolved mineral substances, including sulfates, chlorides, carbonates, and bicarbonates of the elements sodium, calcium, magnesium, and potassium. Although a low level of salts in the soil is desirable, high salinity levels (commonly above an electrical conductivity of 4 decisiemens per meter for many crops) make it difficult for plant roots to extract water from the soil, which may reduce growth rates. High salt concentrations may delay seed germination or completely inhibit germination. The deleterious effects of high salt concentrations are most pronounced among young plants (Donahue et al. 1983).

Bulk Density

Bulk density refers to the mass of dry soil per unit of volume, usually measured in grams per cubic centimeter. Bulk density affects permeability and root penetration and is affected by texture, structure, organic matter content, and soil management practices. Because of differences in these factors, soils with different bulk densities may be effectively equal with respect to permeability and root penetration (Donahue et al. 1983).

Depth

Soil depth affects the capacity of a soil to retain nutrients and metals. References to soil depth pertain to the depth of a soil over rock or a restrictive layer that prevents significant root penetration, such as a hardpan or a very dense claypan. Soils less than 20 inches deep are considered shallow, and soils more than 60 inches deep are considered very deep (U.S. Department of Agriculture 1993).

Organisms

Soil microorganisms, including bacteria, actinomycetes, fungi, algae, and protozoa, play an important role in the decomposition of organic matter (including biosolids) (Phung et al. 1978) and the cycling of plant nutrients, such as nitrogen, phosphorus, and sulfur (National Academy of Sciences 1996). Some evidence suggests that the rate of decomposition of organic matter by microorganisms may be reduced in the presence of high heavy metal concentrations (Sommers et al. 1976). Soil organisms such as earthworms play an important role in breaking up organic materials and mixing them into the soil (Phung et al. 1978).

Drainage

A soil's drainage class is controlled primarily by permeability, seasonal depth of **[or "to"?]** the water table, and slope. At the dry end of the drainage spectrum, soils that are excessively drained tend to be coarse textured, not influenced by high groundwater, and located on steep slopes. Soils that are very poorly drained typically have groundwater at or near the surface for much of the growing season and are located in level or depressional areas (U.S. Department of Agriculture 1993). Sometimes shallow subsurface restrictive layers, such as claypans and hardpans, cause a perched water table (i.e., an area of groundwater that rests on an impermeable layer, preventing water from percolating downward) in the surface soil layers.

Decomposition of organic matter (including biosolids) is typically not restricted by soil moisture if the moisture content is maintained at approximately 30%–90% of the water-holding capacity of the soil. Conversely, saturated conditions (such as in a poorly drained soil) reduce the available oxygen, which can slow microbial decomposition rates. Soil microorganisms become essentially inactive when the soil moisture content drops below the level at which plants wilt (Phung et al. 1978).

Erodibility

Soils most susceptible to erosion (detached and entrained by water and wind) are those high in coarse silt- and fine sand-sized particles (Donahue et al. 1983), particularly when organic matter content is low and soil structure is weak or nonexistent. Erosion is usually of concern when the vegetative cover is removed or reduced, the soil is otherwise disturbed, or both of these conditions exist. Water erosion typically is a less pressing concern on shallow slopes (i.e., 10% or less), such as those generally used for biosolids application, because typically there is little runoff of rainfall. Erosion caused by water is also more easily controlled by maintaining a good vegetative cover. Significant wind erosion can occur in areas with a combination of high winds, removed or disturbed vegetation, fine sandy or silty textures, and low organic matter content.

The erosion rate of a particular soil in the absence of human activities is referred to as the natural or geologic erosion rate. Erosion in excess of the natural erosion rate is called accelerated erosion, which is usually caused by human activities such as cultivation, grazing, and grading.

Summary of Soil Properties by RWQCB Region

Soil conditions in California are extremely variable and reflect a diversity of geologic, topographic, climatic, and vegetative conditions that influence soil formation and composition. For the purposes of this document, broad generalizations can be made about the properties of soils in each RWQCB region that may influence or be influenced by biosolids application. Soil properties that are specific to either a particular region or the biosolids application process are provided, where this information is readily available.

Information Sources

Unless otherwise specified, the following summaries of soil properties in each region were based on Major Land Resource Areas defined by the U.S. Soil Conservation Service (1981) (now the U.S. Natural Resources Conservation Service). Major Land Resource Areas (MLRAs) consist of large areas that are broadly similar with respect to soils, geology, climate, water resources, and land use. Sixteen MLRAs have been designated in the state. MLRA information is appropriate for statewide resource description and planning. This information was supplemented by a general soil map of the state (Pacific Gas and Electric Company 1989) and other literature. Because biosolids are almost always applied on moderate to shallow slopes (i.e., up to approximately 15%), only the types of soil found in valleys, basins, terraces, and alluvial fans are described below.

Soils in the geographic areas excluded from the GO that otherwise would have been included in the discussion (i.e., the Sacramento-San Joaquin River Delta, Suisun Marsh, and the jurisdiction of the San Francisco Bay Conservation and Development Commission) are also not described.

The soils within each RWQCB region were identified by overlaying a map of the region's boundaries over the MLRA map. Table D-1 shows soil properties in California delineated by RWQCB basin areas.

Typical Soil Properties in Forested Areas

Soil properties in forested areas of the state that are suitable for biosolids application (i.e., have less than approximately 15% slope) differ from soils typically used for agricultural land application primarily in that they are underlain by bedrock and are relatively shallow. Forest soils in California tend to have neutral to acidic pH. The organic matter content ranges from relatively low to high (for mineral soils) but is usually concentrated in the upper soil layers. A layer of plant litter often rests on the soil surface. Forest soils are often more strongly leached of nutrients than agricultural soils. The texture typically ranges from clay loam to sandy loam and the soils often have rock fragments in the profile. Except in meadow areas (which typically would not be considered as suitable areas for biosolids application because they may qualify as jurisdictional wetlands) and in seep areas, groundwater tends to be deep (Colwell 1979, U.S. Soil Conservation Service 1981).

Typical Soil Properties at Mined Sites

Conditions at mined sites differ from those at agricultural land application sites in that the native soil material has typically been partially or entirely removed or mixed with less productive subsoil material. Although soil and site conditions may vary widely according to the type of mine, the soil materials at such sites often have low nutrient- and water-holding capacities, high rock-fragment content, low organic matter content, low pH, and high concentrations of trace metals. These conditions result in unfavorable conditions for seed germination and plant growth, making revegetation efforts difficult (Reed and Crites 1984). Slopes may be steep at some mined sites.

Table D-1
Summary of Predominant Soil Characteristics in Each RWQCB Region

RWQCB Region	Depth	Texture	Drainage	Organic Matter Content	Acidity/ Alkalinity	Other Distinguishing Characteristics
1	shallow to deep (the former sometimes over a subsurface cemented hardpan)	sandy to clayey	well drained to poorly drained	low to high	moderately acid to neutral	Owing to the presence of serpentine rocks, upland soils in the region contain high amounts of nickel and copper (Holmgren et al. 1993); gently sloping alluvial soils below the serpentine watersheds may also contain high background concentrations of the two metals.
2	deep	loamy to clayey	well drained to poorly drained	moderate to high	slightly acid to slightly alkaline	
3	very deep	sandy to clayey	well drained to poorly drained	moderate to high	slightly acid to slightly alkaline	Some alluvial soils, lying below certain areas of Monterey shale, in the Salinas Valley have been reported to contain high background concentrations of cadmium (Holmgren et al. 1993).
4	shallow to deep (the former sometimes over a subsurface cemented hardpan)	loamy	well drained	moderate to high	slightly acid to slightly alkaline	

Table D-1. Continued

5	shallow to deep (the former sometimes over a subsurface cemented hardpan)	sandy (particularly along the eastern side of the San Joaquin Valley) to clayey	well drained to poorly drained	moderate	moderately acid to alkaline	Some areas along the western side of the San Joaquin Valley, have high selenium, boron, molybdenum, and arsenic (the latter in the extreme southern end) and salt concentrations (all of which occur naturally in the soils) in soils and groundwater, and high groundwater levels (San Joaquin Valley Drainage Program 1990). High concentrations of mercury have been identified in soils of the Panoche and Cantua Creeks alluvial fans (Tidball et al. 1986).
6	moderately deep	sandy to loamy	low rainfall causes the soils to be droughty	low	neutral to alkaline	Some soils have high calcium content
7	moderately deep to very deep	sandy to clayey	low rainfall causes the soils to be droughty	low	neutral to alkaline	Some areas have high salt (Letey et al. 1996) and calcium content. Wind erosion is a major issue in this region.
8	shallow to deep (the former sometimes over a subsurface cemented hardpan)	loamy	well drained	moderate to high	slightly acid to slightly alkaline	
9	shallow to deep (the former sometimes over a subsurface cemented hardpan)	sandy to loamy	well drained	low to moderate	slightly acid to slightly alkaline	

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Notes:

1) The information provided in this table consists of generalizations about the predominant soils occurring in each RWQCB region; soils with characteristics different than those described above may also occur.

2) Because biosolids are nearly always applied on moderate to more shallow slopes (i.e., up to approximately 15%), only those soils occurring in valleys, basins, terraces, and alluvial fans are described. Additionally, soils occurring in the larger geographic areas excluded from the GO that otherwise would have been

included in the table (i.e., the Sacramento-San Joaquin Delta, the Suisun Marsh, and the jurisdiction of the San Francisco Bay Conservation and Development Commission) are also not described.

Sources: U.S. Department of Agriculture Soil Conservation Service 1981, Pacific Gas and Electric Company 1989.

Typical Soil Requirements of Horticultural Operations

In California, biosolids are not widely used for horticultural plantings. It is expected that the most frequent uses would be in large parkland or golf course settings or in large-scale nursery operations. These settings could occur throughout the state but would likely be more common in valley or low foothill areas with relatively deep soils, moderate to shallow slopes (less than 15%), and a wide range of soil textures (coarse silts to clay loams and clays). Because horticultural areas are usually selected for their ability to support planted vegetation, they usually have low to medium organic content, are well drained, and have a pH ranging from slightly alkaline to slightly acidic. Soil conditions that would be unfavorable for seed germination and plant growth would be avoided. Where new parks or golf courses are being developed, biosolids may be applied to soil material imported from offsite. These soils may lack profile development and have little or no remaining soil structure.

Environmental Setting for Hydrology

Surface Water Hydrology

The surface waters of California can best be characterized by regions of similar hydrologic character. Six separate hydrologic regions have been designated in the state, based on divisions established by the California Department of Water Resources (DWR) (1994a). Each of these regions exhibits distinct precipitation, runoff, and geologic conditions. Because of vast differences in climate, vegetation, and geography between these regions, the state possesses wide-ranging variations in seasonal weather patterns, precipitation, and runoff potential. A variety of database resources are available, and new information is constantly being added that allows evaluation of site-specific hydrologic characteristics in California. With the advent and expansion of available Internet resources, computer databases now include extensive data from geographic information systems (GIS) databases such as those maintained by the California Teale Data Center for topography, watershed boundaries, surface water and groundwater resources, designated floodplains, geological features, soil characteristics, and vegetative cover (California Teale Data Center 1999). Databases are also available for specific streamflow information for gaged rivers in California on the U.S. Geological Survey Internet servers (U.S. Geological Survey 1999a). The DWR operates the California Irrigation Management Information System (CIMIS), a program of real-time atmospheric and precipitation data aimed at water management for agricultural operations (California Irrigation Management Information System 1999). DWR also maintains the California Data Exchange Center (CDEC) program of real-time data collection for river, reservoir, and snowpack information focused on water supply management (California Data Exchange Center 1999).

Characteristics of California Watersheds

High amounts of variation in climate, precipitation, and runoff characteristics dominate California watersheds. The North Coast region, for example, can receive up to 200 inches of rainfall per year, whereas some areas of the Colorado Desert region in the south part of the state receive less than 2 inches per year (Mount 1995). These patterns, combined with other regional factors, determine the amount and type of runoff emanating from the area, the rate of deep percolation and aquifer recharge, and the potential for flooding to occur. Table D-2 shows the seasonal patterns, precipitation and runoff characteristics of the six regions.

Water Supply Issues. The state is traversed by numerous facilities and infrastructure to ensure that water supplies are reliable. A water service system's reliability is based on that system's ability, through proper management, to meet demand regardless of fluctuations in supply, including shortages during periods of drought (California Department of Water Resources 1994a).

Of the 62.4 million acre-feet (maf) of total projected available supplies for the year 2000 (non-drought scenario), 55.1 maf is surface water for local and long-range deliveries and dedicated natural flow. A significant portion of the surface water originating in northern California is transferred through Central Valley Project (federal) and State Water Project operations to southern California from the Sacramento-San Joaquin River Delta, from the Mono-Owens Lake area in eastern California, and from the Colorado River (California Department of Water Resources 1994a). Table D-3 describes the major watersheds, surface water resources, and conveyance facilities in each Regional Water Quality Control Board (RWQCB) region.

Legislative and policy changes in federal and state deliveries and uses over the past 8–10 years have created a greater demand for optimal management of the state's water resources. More of the water is designated for environmental purposes, and mandates to reduce impaired water bodies have been reinforced. To meet these increased standards, long-term, comprehensive management programs are being developed and implemented throughout the state. Conserving water and maintaining the quality of existing water supplies are now the focuses for resource management and regulatory agencies, water supply purveyors, treatment plant operators, and users.

Groundwater Hydrology

Approximately 40% of the total land area of the state is underlain by groundwater basins. It is estimated that the storage capacity of these basins reaches totals of approximately

Table D-2.
Watershed Characteristics of California

Region	Seasonal Patterns	Runoff Characteristics	Precipitation
North Coast (Region 1)	Inland: Distinct rainy, cool winters and hot, dry summers. Coastal: Cool and wet year round with little temperature variation.	Highest peak discharges recorded in state, with highest total sediment yields.	Dominated by rainfall; average annual precipitation in region is 53 inches.
Sacramento, San Joaquin, and Tulare Lake (Region 5)	Valley: Hot, dry summers and cool, wet winters. Mountains: Mild summers with intermittent thundershowers, heavy winter snowfalls above 5,000 feet.	Prolonged spring runoff fed by Sierra Nevada snowpack; low sediment yields due to widespread vegetation and stable rock types/soils; locally high sediment yields due to land uses (e.g., logging, grazing, and urbanization).	Valleys receive winter rainfall, and mountains receive moderate to heavy snowfall; total average annual precipitation ranges from 36 inches in the Sacramento River region to 13-14 inches for the San Joaquin and Tulare Lake regions.
San Francisco Bay and Central Coast (Regions 2 and 3)	Coast: Cool and foggy year round with rain in the winter; small seasonal temperature variations Inland areas: Warm, dry summers with cool, rainy winters.	High peak runoff due to small, steep watersheds; local rivers susceptible to severe flooding during high-rainfall events; some watersheds produce high sediment yields due to unstable rock types/soils	Precipitation from rainfall, with insignificant snowfall; northern area - average annual precipitation is 31 inches, greater than 50 inches in some areas; southern area - average precipitation is 20 inches
North and South Lahontan (Region 6)	Valleys: Semi-arid, high-desert terrain; hot, dry summers with locally intense thunderstorms; mild, dry winters Mountains: Cool, mild summers; cold winters with regionally heavy snowfall	Valleys: High peak runoff in ephemeral drainages; watersheds except Owens River are short and steep ephemeral drainages; stable rock types/ soils result in low, coarse sediment yields Mountains: Extended spring runoff with locally high sediment yields in Sierra Nevada.	Valleys: Low to moderate precipitation totals due to rainshadow effects of Sierra Nevada and Cascade Mountains Mountains: Regionally heavy winter snowfall and intense summer thunderstorms; average annual precipitation ranges from 8 inches in the south to 32 inches in the north

Table D-2. Continued

Region	Seasonal Patterns	Runoff Characteristics	Precipitation
South Coast (Regions 4, 8, and 9)	Mediterranean climate with several dry years interrupted by infrequent high precipitation years; warm, dry summers and mild, wet winters; inland summer temperatures can exceed 90ºF; intense subtropical storms	Watersheds are largely ephemeral and fed by rainfall; rivers susceptible to frequent flooding due to peak discharge events; sediment yields are locally high due to intense urbanization, low vegetation, and unstable soils; debris flows and mudflows frequent in some smaller drainages	High rainfall with insignificant snowfall contribution; locally heavy storms have the highest 24-hour rainfall totals in the state; average annual precipitation is 18.5 inches
Colorado Desert (Region 7)	Arid desert region with hot, dry summers and mild winters; rainfall is limited to a few storms per year	Low runoff due to limited rainfall, but locally heavy during infrequent storm events; overall sediment yields are low but produce debris flows during storms	All precipitation falls in the form of rain; region has the lowest yearly precipitation totals in the state, with some areas receiving less than 2 inches; average regional rainfall is 5.5 inches.

Sources: Mount 1995; California Department of Water Resources 1994a; California Regional Water Quality Control Board 1994.

Table D-3.
Principal Surface Water Resources, Water Supply Facilities, and Beneficial Uses for Each RWQCB Region

Region	Primary Basins or Contributing Rivers	Major Storage Facilities (Reservoirs)	Major Conveyance Facilities	Sensitive Beneficial Uses	Central Valley Project (CVP) Supply Status	State Water Project (SWP) Supply Status	Notes
1- North Coast	Klamath River Basin, North Coast Basin	Clair Engle (Trinity), Upper Klamath (Oregon), Clear Lake, Lake Sonoma Warm Springs Dam	Canal from Clair Engle Reservoir to northern Sacramento Valley	Municipal, domestic and industrial supply, recreation, maintenance of resident and anadromous fisheries, national wildlife refuges	No CVP supplies to area	No SWP supplies to area	Area contains most of the state's wild and scenic rivers. 95% of supplies dedicated to environmental use.
2 - San Francisco Bay	Numerous local surface water drainages	Calaveras, Leroy Anderson, Del Valle, Briones, Crystal Springs	Putah South Canal, Sonoma-Petaluma Aqueducts, North Bay Aqueduct, Mokelumne Aqueduct, Contra Costa Canal, South Bay Aqueduct, Hetch Hetchy Aqueduct, San Felipe Unit	Municipal, domestic and industrial supply, groundwater recharge, water recreation , wildlife, cold and warm freshwater habitat, fish migration and spawning, estuarine habitat	CVP water delivered through the Contra Costa Canal to the Contra Costa Water District and through the San Felipe Project to the Santa Clara Water District. About 50% is used for recharge, the rest is used for direct supply	SWP water delivered through the South Bay Aqueduct to the Santa Clara Valley Water District for municipal and industrial supply, agricultural deliveries, and groundwater recharge	76% of supplies are for dedicated natural flow

Region	Primary Basins or Contributing Rivers	Major Storage Facilities (Reservoirs)	Major Conveyance Facilities	Sensitive Beneficial Uses	Central Valley Project (CVP) Supply Status	State Water Project (SWP) Supply Status	Notes
3 - Central Coast	Numerous local surface water drainages	San Antonio, Nacimiento, Cuyama River, Santa Ynez. Over approximately 60 reservoirs. Most are privately owned	San Felipe Unit, Coastal Branch Aqueduct	Wildlife, municipal, domestic, and industrial supply, recreation, rare, threatened or endangered species	CVP water delivered through the San Felipe Unit	SWP water delivered through the Coastal Branch Aqueduct	82% of water supplies from groundwater, remainder of non-CVP/SWP supplies from local surface water and storage facilities.
4 - Los Angeles	Santa Clara River, Los Angeles River, San Gabriel River	Castaic Lake, Lake Piru, Pyramid Lake, Lake Casitas	Los Angeles Aqueduct, California Aqueduct	Municipal, domestic, and industrial, agricultural, recreation, warm and cold freshwater habitat, wildlife habitat, rare, threatened or endangered species	No CVP deliveries in region	SWP water delivered through the California Aqueduct. Supplies nearly one-half of the surface water deliveries in the region.	Water also delivered through the Colorado River Aqueduct (supplies comparable amount as the California aqueduct). About 26% of all water supplies come from groundwater resources.

Region	Primary Basins or Contributing Rivers	Major Storage Facilities (Reservoirs)	Major Conveyance Facilities	Sensitive Beneficial Uses	Central Valley Project (CVP) Supply Status	State Water Project (SWP) Supply Status	Notes
5 - Central Valley	Sacramento River Basin and, San Joaquin River Basin (both contain numerous important watersheds)	Numerous large reservoirs in the Sierra range (capacities of 200 thousand acre-feet or more); several smaller reservoirs along east side of coast range	California Aqueduct (i.e., SWP), Delta-Mendota Canal (i.e., CVP), Friant-Kern Canal, numerous canals and ditches on valley floor	Agriculture, wildlife habitat, fish migration and spawning, preservation of rare and endangered species, warm and cold freshwater habitat, municipal, domestic, and industrial,	Projected water supplies from CVP operations are projected to be about 7.4 million acre-feet in the year 2000 (average year)	SWP supplies insignificant in northern and central valleys. Tulare Lake region is projected to receive just over 1 million acre-feet of water in the year 2000 (average year)	Other local surface water and groundwater supplies are projected to be 13.7 million acre-feet in the year 2000 (average year). Region supplies over 2/3 of the state's drinking water needs.
6 - Lahontan Region	Truckee River, Carson River, Walker River, Owens River, Amargosa River, Mojave River	Stampede, Lake Tahoe, Lake Crowley	California Aqueduct (east and west branches), Los Angeles Aqueduct	Agriculture, wildlife habitat, warm and cold freshwater habitat, municipal, domestic, and industrial	No CVP deliveries in region	Supplies from SWP facilities are projected to total about 24% of all developed water supplies in South Lahontan. No SWP facilities in North Lahontan.	North Lahontan receives 74% of all water supplies from local surface water, and 23% from groundwater. South Lahontan receives 10% of supplies from local surface water, 52% from groundwater, and 23% is dedicated natural flow

Region	Primary Basins or Contributing Rivers	Major Storage Facilities (Reservoirs)	Major Conveyance Facilities	Sensitive Beneficial Uses	Central Valley Project (CVP) Supply Status	State Water Project (SWP) Supply Status	Notes
7 - Colorado River Basin	Colorado River, White Water River	Salton Sea - saline	Colorado River Aqueduct, California Aqueduct, Coachella Canal, East Highline Canal, Westside Canal	Agriculture, municipal and industrial, recreation	No CVP deliveries in region	Small amount (2% of all supplies) provided through SWP deliveries	96% of all water supplies delivered to the region are conveyed from the Colorado River Aqueduct (year 2000 projection, non-drought scenario)
8 - Santa Ana	Santa Ana River	Lake Perris, Lake Mathews, Lake Elsinore, Seven Oaks, Prado	Colorado River Aqueduct	Municipal, domestic, and industrial, agricultural, recreation, warm and cold freshwater habitat, wildlife habitat, rare, threatened or endangered species	No CVP deliveries in region	SWP water delivered through the California Aqueduct. Supplies nearly one-half of the surface water deliveries in the region.	Water also delivered through the Colorado River Aqueduct (supplies comparable amount as the California aqueduct). About 26% of all water supplies come from groundwater resources.

Table D-3. Continued

Region	Primary Basins or Contributing Rivers	Major Storage Facilities (Reservoirs)	Major Conveyance Facilities	Sensitive Beneficial Uses	Central Valley Project (CVP) Supply Status	State Water Project (SWP) Supply Status	Notes
9 - San Diego	San Luis Rey River, San Diego River	San Vicente Reservoir, Lower Otay Lake, El Capitan,	Colorado River Aqueduct, San Diego Aqueducts	Municipal, domestic, and industrial, agricultural, recreation, warm and cold freshwater habitat, wildlife habitat, rare, threatened or endangered species	No CVP deliveries in region	SWP water delivered through the California Aqueduct. Supplies nearly one-half of the surface water deliveries in the region.	Water also delivered through the Colorado River Aqueduct (supplies comparable amount as the California aqueduct). About 26% of all water supplies come from groundwater resources.

1.3 billion acre-feet of water, and many of them are estimated to be full or nearly full. The fraction of water that is usable from these basins, about 143 million acre-feet, is still more than three times the capacity totals of the state surface storage reservoirs.

Many of the California groundwater basins are located in arid valleys and are recharged by percolation of rainfall and surface water flows. Recharge occurs more readily in areas of coarse sediments, which are usually located near the alluvial fans associated with mountain ranges. Percolation in southern California occurs only during periods of intense precipitation, whereas northern California groundwater basins often receive direct recharge from annual precipitation (California Department of Water Resources 1975). The location and extent of impermeable confining layers in the alluvial deposits that contain the aquifers play a major role in the amount and rate of recharge of percolating water, and overall quality of the groundwater.

Groundwater Basins

There are about 250 important groundwater basins statewide, supplying about 40% of the state’s applied water needs. Statewide, more than 15 million acre-feet (maf) of groundwater are extracted for use in agricultural, municipal, and industrial applications. Table D-4 identifies California’s major groundwater basins by region. For types of sensitive beneficial uses of water by region, refer to Table D-2.

Water Quality Setting

Surface Water and Groundwater

State and federal water quality standards are established to achieve a level of quality that provides the highest benefit for all users. Therefore, water resources need to be protected from impairments that result from waste discharges. By assessing and identifying beneficial uses in a given area, water quality standards and treatment levels can be established to best meet the needs of that area. The primary beneficial uses that are evaluated for regulatory compliance (refer to “Regulatory Framework” below) include aquatic life support, fish consumption, primary-contact recreational activities such as swimming, secondary-contact recreational activities such as wading, drinking water supply, and agricultural/industrial supply. The costs of remedial cleanup actions and potential adverse environmental effects of poor water quality can be considerable and can affect the amount of water available for beneficial uses. Increased storage, treatment, and handling costs; reduced crop yields; and harmful effects on fish and wildlife are examples of the adverse effects of impaired waters.

Table D-4. Major Groundwater Basins of California

Region	Major Groundwater Basins	Extraction (ac-ft/yr)
1 - North Coast	Tule Lake, Siskiyou Butte Valley, Shasta Valley, Scott River Valley, Hoopa Valley, Smith River Plain, Mad River Valley, Eureka Plain, Eel River Basin, Covelo Round Valley, Mendocino County	242,338
2 - San Francisco Bay	Petaluma Valley, Napa-Sonoma Valley, Suisun-Fairfield Valley, Santa Clara Valley, Livermore Valley, Marin County, San Mateo County	190,128
3 - Central Coast	Soquel Aptos, Pajaro Basin, Salinas Basin, S. Santa Clara - Hollister, Carmel Valley-Seaside, Arroyo Grande/Nipomo Mesa, Cuyama Valley, San Antonio, Santa Ynez Valley, South Central Coast, Upper Salinas, San Luis Obispo	1,075,800
4 - Los Angeles	Central Basin, West Coast Basin, San Fernando Valley, Raymond Basin, San Gabriel, Upper Ojai Valley, Fox Canyon	808,000
5 - Central Valley	Butte County, Colusa County, Tehama County, Glenn County, Sacramento County, Western Placer County, Yuba County, Sutter County, Eastern Solano County, Yolo County, Sierra Valley, Goose Lake Basin, Big Valley, Fall River Valley, Redding Basin, Almanor Lake Basin, Upper Lake Basin, Lake County/Scotts Valley, Kelseyville, Valley Basin, Coyote Valley, Middletown-Colalyomi Valley, San Joaquin County, Modesto Basin, Turlock Basin, Merced Basin, Chowchilla Basin, Madera Basin, Delta Mendota, Kings Basin, Tulare Lake Basin, Kaweah Basin, Tule Basin, Westside Basin, Pleasant Valley Basin, Kern County Basin	8,302,100
6 - Lahontan	Surprise Valley, Honey Lake Valley, Long Valley Basin, Thermo-Madeline Plains, Willow Creek Valley, Secret Valley, Owens Valley, Death Valley, Mojave River Valley, Antelope Valley	397,200
7 - Colorado River	Warren Valley, Coachella Valley, Cuckwalla	114,740
8 - Santa Ana	Orange County (also in Region 9), San Bernardino Basin Area, Riverside Basin Areas 1 and 2, Colton Basin	98,180
9 - San Diego	Temecula Valley, San Juan Valley, El Cajon Valley, Sweetwater Valley, Otay Valley, Warner Valley, San Luis Ray	34,000*

*Total does not include Warner Valley or San Luis Ray - extraction rates unknown.
Sources: California Department of Water Resources (1994a), and California Department of Water Resources (1975).

Water quality is monitored through a variety of federal, state, and local programs. The state evaluates current water quality conditions and prioritizes funding efforts for protection, cleanup, and monitoring programs through individual water quality assessments, which are compiled into the state's Section 305(b) reporting process mandated under the federal Clean Water Act (California State Water Resources Control Board 1996). The Section 305(b) report includes the Section 303(d) lists, which are named in reference to the Clean Water Act section that mandates their preparation. The Section 303(d) lists identify water bodies that do not meet applicable water quality standards for designated beneficial uses with technology-based controls for waste discharges. Several other major ongoing water quality monitoring programs include the State Toxics Substance Control Monitoring Program (California State Water Resources Control Board 1999) and monitoring that is required to be conducted in the San Joaquin-Sacramento River Delta to manage SWP and CVP operations in the Central Valley (California Department of Water Resources 1994b, California Department of Water Resources 1999). Databases are also available for specific water quality information for many rivers, lakes, and groundwater wells in California on the U.S. Environmental Protection Agency's (EPA's) STORET data retrieval system (EarthInfo Inc. 1994, U.S. Environmental Protection Agency 1999) and U.S. Geological Survey Internet servers (U.S. Geological Survey 1999b).

Water quality issues differ depending on the location and type of water resource, size and extent of the watershed and water resources, location with respect to potential pollutant sources, and season and climatic factors, as well as many other interacting physical, chemical, and biological processes. Medium to large surface water bodies typically have a large capacity to assimilate waste loads of pollutants because various physical and chemical processes are effective in diluting and transforming pollutants to less harmful components. Biological processes are especially important because many chemical constituents can be absorbed by plants or animals and removed from the water or metabolized in biological tissues to less harmful substances. Consequently, water quality impairment at a large scale usually occurs in watersheds with extensive development for human activities that receive pollutants from a variety of point- and nonpoint-source pollutant discharges. Point-source pollution refers to discharges from a single location, such as a wastewater treatment plants, landfill, or industrial site. Nonpoint-source discharges are generated over a large area and result from dispersed activities such as urban stormwater runoff; mining, agricultural and forestry activities, residential septic tanks, or accidental spills.

Surface water quality is primarily dependent on seasonal flow and hydrologic patterns in combination with the mineral composition of the watershed soils and associated parent materials, topography, and sources of contaminants. During summer low-flow conditions, the water quality characteristics of most importance to aquatic life are temperature, dissolved oxygen, turbidity, biostimulatory nutrients (e.g., nitrogen and phosphorus) and nuisance algae growth, and toxic constituents such as un-ionized ammonia or residual chlorine. During higher winter streamflow conditions, water quality is influenced more by stormwater runoff and associated pollutants, such as eroded soil, oil and grease from automobiles and paved areas, nutrients from agricultural fields and livestock boarding areas, and organic litter (e.g., leaves and grass clippings).

The most recent state Section 305(b) report indicates that most of the state's surface lakes and reservoirs, rivers and streams, freshwater wetlands, and estuaries only partially support all of their designated beneficial uses. Of the water bodies not supporting all of their uses, a small fraction fail to support the designated beneficial uses all the time. For example, 10,838 miles of the rivers and streams only partially support all beneficial uses; however, only 2,142 miles fail to support one or more beneficial uses all of the time. For lakes and reservoirs, approximately 569,000 acres only partially support beneficial uses, but only 9,670 acres fail to support one or more uses all of the time. For freshwater wetlands, approximately 107,000 acres partially support beneficial uses but there are no wetlands that do not support a beneficial use all the time. The Section 305(b) report also provides a listing of the physical or chemical constituents that cause impairment of beneficial uses. Lake and reservoir beneficial uses tend to be impaired predominantly by the presence of noxious weeds, trace metals, pesticides, and taste and odor problems, with each constituent affecting at least 100,000 acres. Approximately 30,000 acres are impaired by organic enrichment and dissolved oxygen effects, 12,000 acres are affected by nutrients and general eutrophication problems, and 12,000 acres are affected by siltation. Smaller acreages are affected by unknown toxicity, flow alterations, un-ionized ammonia, pH, or unknown causes. Rivers and streams tend to be affected by a much larger variety of constituents. Siltation, pathogens, pesticides, and trace metals dominate the list of problem constituents, with each affecting more than 3,000 miles of channels. Debris, organic enrichment, habitat alterations, salinity, suspended solids, and other trace elements each affect more than 1,000 miles of channel. Freshwater wetlands tend to be impaired primarily by trace metals, salinity, and other trace elements, with each affecting more than 8,000 acres. Flow and habitat alterations, nutrients, pesticides, and siltation contribute to the problems less sizeably. Table D-5 summarizes the major water quality issues for surface water and groundwater resources affecting each of the nine RWQCB regions.

Groundwater quality has typically been less of a concern than surface water quality because many of the useable aquifers for domestic consumption were protected by the overlying soils and geological structures. Groundwater quality, when impaired, was typically associated with percolation from landfills, leaking underground tanks, or other readily identified source of pollution. However, the public attention and regulatory focus of managing and protecting groundwater quality are increasing because nonpoint sources are known to cause widespread impairment of groundwater quality through the introduction of inorganic contaminants such as nitrates from septic tanks and agricultural fertilizer use, large scale use of pesticides and herbicides, and major concerns still exist over the potential infiltration of hazardous wastes from historical land uses. The most recent state 305(b) report indicates that approximately 20,000 acres of groundwater basins only partially support all beneficial uses, however, only 1,150 acres fail to support one or more beneficial uses all of the time. Approximately 24,800 acres of groundwater

Table D-5. Major Water Quality Issues Affecting Beneficial Uses

Region	Surface Water Issues	Sources	Groundwater Issues	Sources
1 - North Coast	Sedimentation	Logging, Grazing	n/d	n/d
2 - San Francisco Bay	Sedimentation, eutrophication, elevated fish tissue levels, dissolved solids, trace metals, habitat degradation, toxic pollutants	Irrigated farm runoff, stormwater runoff, sewage discharges, industrial manufacturing	Threat of drinking water impairment, saline intrusion, synthetic organics	Irrigated farm runoff and other nonpoint sources, overdraft, tank leaks and industrial discharges
3 - Central Coast	Sedimentation, wildlife and fisheries impairments, trace metals	Irrigated farm runoff, nonpoint urban runoff	Drinking water impairment, saline intrusion, nitrates, toxic pollutants	Nonpoint source runoff, groundwater overdraft
4 - Los Angeles	Elevated tissue levels, nutrients, sedimentation, high coliform count, trace metals, salinity ammonia	Industrial and urban discharges and runoff, diversions, sewage discharges, illegal dumping	Nitrates, synthetic organics, salinity, VOCs, saline intrusion	Industrial manufacturing, nonpoint source runoff, overdraft
5 - Central Valley	Sedimentation, elevated fish tissue levels, eutrophication, aquatic habitat degradation, drinking water impairment, potential THM precursors	Irrigated agriculture, diversions, municipal and industrial discharges, mineral exploration and extraction	Drinking water impairment, pesticides and herbicides, agricultural impairment, VOCs	Irrigated agriculture, dairy nonpoint source pollution, agricultural wastewater, fuel tank leaks, overdraft
6 - Lahontan	Recreational impacts, threats to rare and endangered species, eutrophication, sedimentation, fish kills, metals	Hydrologic modifications, grazing, mining drainage, agricultural runoff and wastewater	Drinking water impairment, salinity, VOCs	Mining drainage, overdraft, fuel tank leaks

Table D-5. Continued

Region	Surface Water Issues	Sources	Groundwater Issues	Sources
7 - Colorado River	Sedimentation, salinity, threat of drinking water impairment, bacteria, pesticides and herbicides	Agricultural runoff and wastewater, erosion, diversions	VOCs, threat of drinking water impairment	Overdraft, fuel tank leaks,
8 - Santa Ana	Elevated shellfish tissue levels, threat of toxic pollutants, eutrophication, sedimentation, potential THM precursors, trace metals, ammonia	Agricultural wastewater, industrial discharges, urban stormwater runoff	Drinking water impairment	Agricultural nonpoint source runoff
9 - San Diego	Sedimentation, eutrophication, high coliform counts, metals	Municipal and industrial discharges and runoff, agricultural irrigation returns, mining operations	Salinity, nitrates, organics, metals	Overdraft, underground storage tank leaks

Sources: Regional Water Quality Control Board Basin Plans (California Regional Water Quality Control Boards 1995); California Water Quality Assessment Report (1996), California Department of Water Resources (1994a).
Notes: n/d = no data available;

have elevated levels of toxic constituents. A more detailed analysis of existing groundwater contamination issues associated with nitrates is presented below.

Nitrate in Groundwater and Nitrate-Sensitive Areas

Nitrogen may be a factor in limiting the quantity of land available for biosolids application in any specific area. Nitrate contamination of groundwater has been documented throughout California (California State Water Resources Control Board 1988, California Department of Food and Agriculture 1989). Nitrogen is present in groundwater primarily in the nitrate form, although minor amounts of ammonium or nitrite may be present. The California drinking water standard or maximum contaminant level (MCL) is 45 milligrams per liter (mg/l) of nitrate (NO_3). This is approximately equivalent to the state and federal drinking water standard of 10 mg/l nitrate as expressed as nitrogen (NO_3-N).

Increased nitrate levels can be attributed to increases in population and food production. Potential sources of nitrate contamination include human and animal waste and nitrogen fertilizers used for production agriculture and in municipal areas. Nitrate is a nonpoint-source contaminant. The largest nonpoint source of nitrate contamination to groundwater is fertilizers applied in commercial farming (California State Water Resources Control Board 1988). Potential groundwater contamination from nitrates is related to many complex factors that influence biological conversions and the physical processes by which nitrates are transported through the subsurface environment. These factors include soil characteristics, crop, irrigation practices, timing and application of nitrogen, geology, climate, and hydrologic conditions. It is difficult to determine whether an observed level of nitrates in groundwater results from current or past operations. It is also difficult to quantify the level of nitrate contribution from the potential sources (agricultural, animal waste, septic, or wastewater sources).

The most recent statewide compilation of nitrate conditions in groundwater by geographic area in California was produced in 1988 (California State Water Resources Control Board 1988). The data were compiled through contact with each of the nine RWQCBs, contact with county health directors, the California Department of Health Services (DHS), the California Department of Food and Agriculture (DFA), the U.S. Geological Survey (USGS), and EPA. State and federal databases and a literature search were conducted. The SWRCB found that a large body of data exists and that special investigations were being conducted at the local level, but determined that information was not readily available for use in a statewide assessment. Large data gaps were found to exist because of the different types of monitoring programs being conducted, and there was no readily accessible centralized source for making assessments of nitrates in groundwater. For any thorough investigation of nitrate loading at the scale of an individual groundwater basin, it would be imperative to have close contact with local agencies and with the studies being conducted at this level. In general, the data and research available suggest that the highest potential for subsurface transfer of surface-applied nitrogen to groundwater would be in highly permeable, sandy soils with low organic matter content under heavy irrigation, and that shallow wells were the water resource most susceptible to impairment. Areas that do not receive a large amount of freshwater recharge also may act as "sinks" that are more susceptible to cumulative loading of nitrates.

Figure D-1 shows well locations in areas throughout the state that have recorded nitrate levels of 45 mg/l or more during 1975–1987. Figure D-2 shows well locations where nitrate levels have been recorded in the range of 20–44 mg/l during the same period (California State Water Resources Control Board 1988). There is no statewide compilation more current than the 1988 SWRCB report, although water quality assessments prepared by each RWQCB also evaluate the level of impairment from nitrates to the designated beneficial uses for specific surface water bodies and groundwater basins.

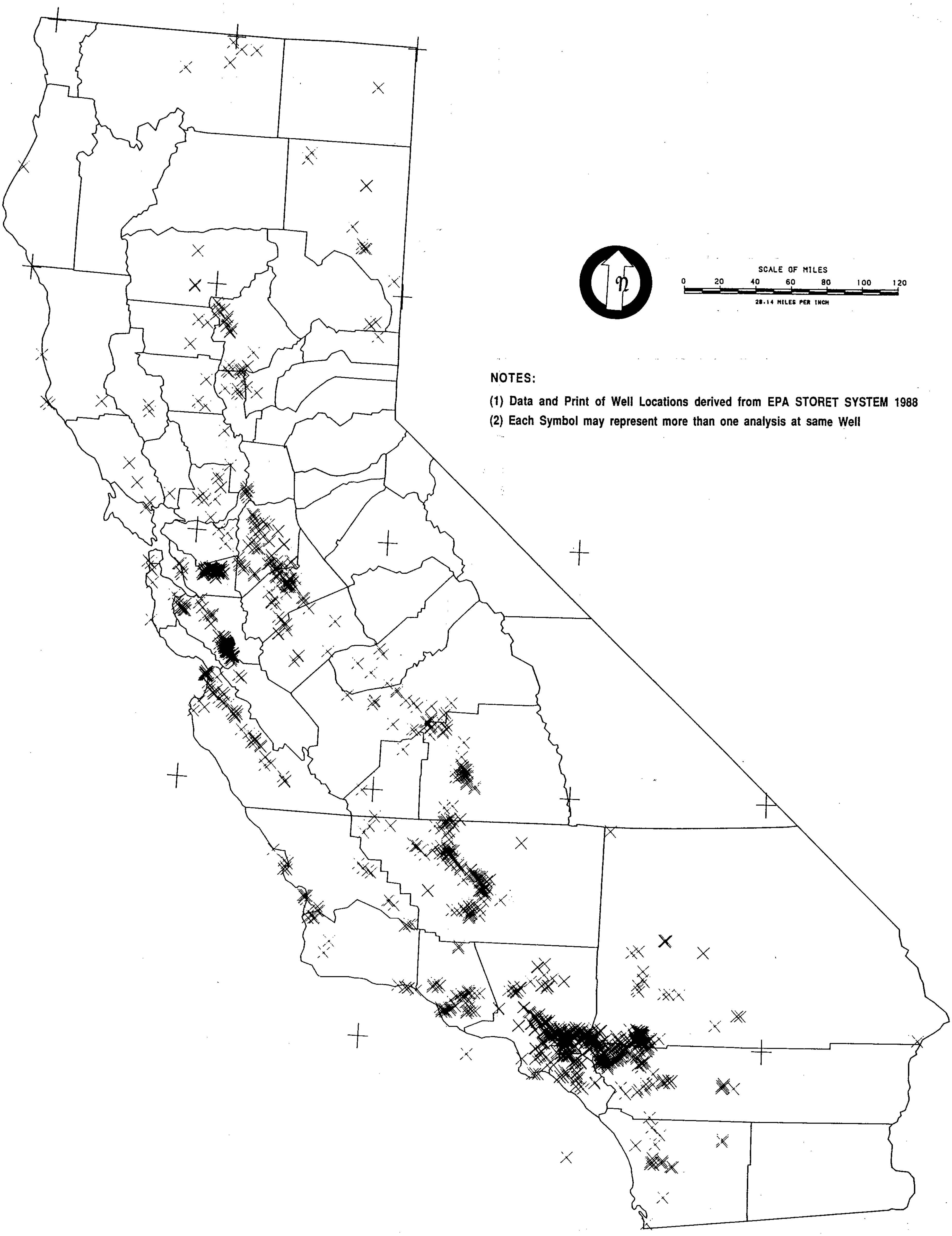
DFA has developed criteria for evaluating nitrate-sensitive areas to prioritize funding and research on nitrates (California Department of Food and Agriculture 1998). Two conditions indicate an urgent problem: a high level of nitrate contamination in groundwater and a population that depends on that water for drinking. Those two conditions depend on various factors. Soil scientists with the University of California and DFA's Fertilizer Research and Education Program (FREP) identified seven criteria for assessing the nitrate sensitivity of an area:

- **Groundwater use:** Nitrate concentration is critical if groundwater is used for domestic or animal drinking supplies.

- **Soil properties:** Sandy or other coarse-textured soils transmit water containing dissolved nitrates downward more rapidly. Also, these soils are less likely to create conditions in which nitrate turns to a gas and escapes from the soil (denitrification).

- **Irrigation practices:** Inefficient irrigation systems that lead to large volumes of subsurface drainage increase the leaching of nitrates. Typically, these are surface flow systems with long irrigation runs. Well-managed sprinkler or drip systems and surface flow systems with short runs reduce the threat of nitrate leaching to groundwater.

- **Type of crop:** Crops most likely to increase nitrate leaching are those that (1) need heavy nitrogen fertilization and frequent irrigation; (2) have high economic value, so that the cost of fertilizer is relatively small compared to the revenue produced; (3) are not harmed by excess nitrogen; and (4) tend to take up a small fraction of the nitrogen applied. Many vegetable, fruit, nut, and nursery crops fit these criteria and, therefore, have elevated potential for nitrate leaching. Those with less potential include field crops such as alfalfa, wheat, and sugar beets.



Source: State Water Resources Control Board 1988.

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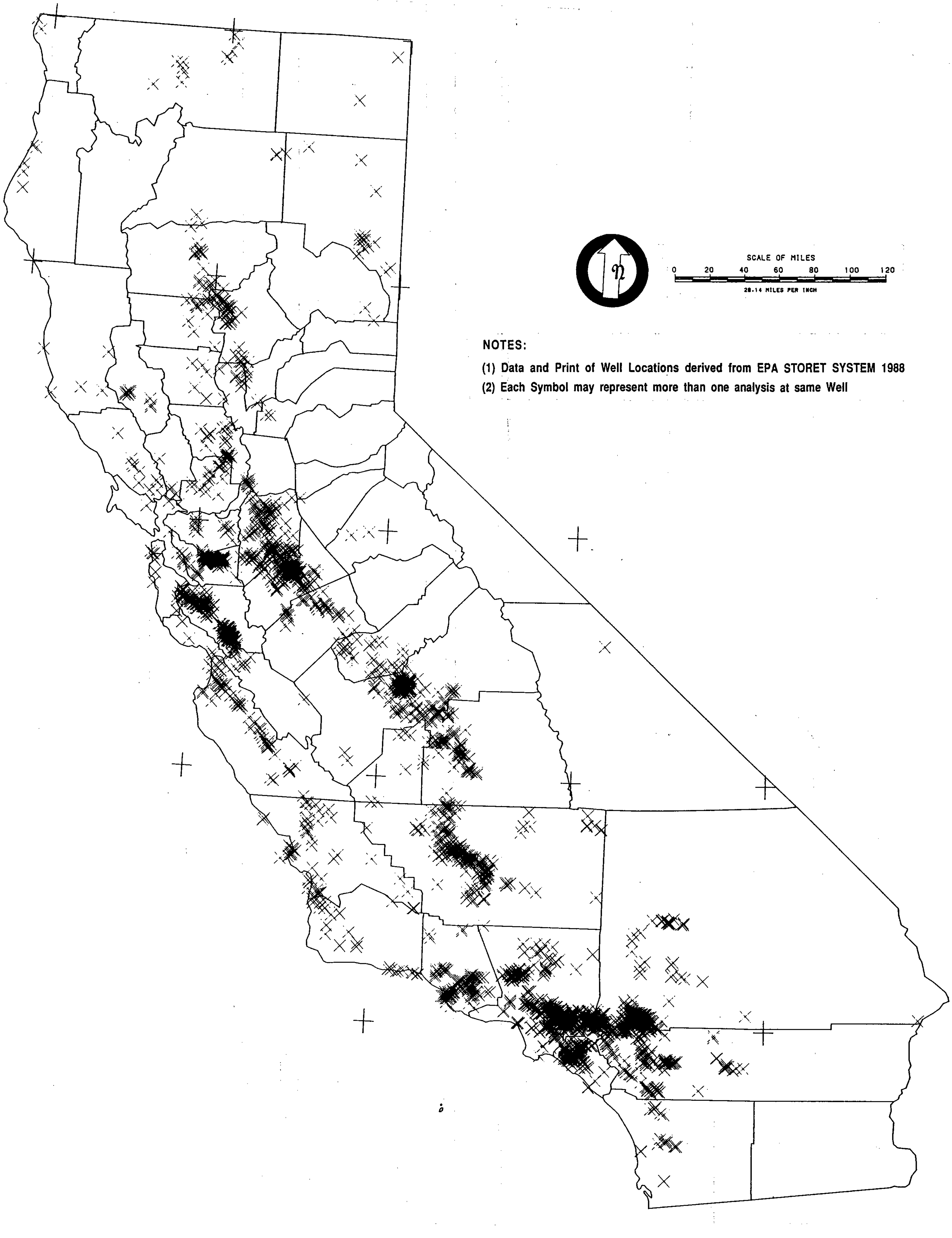
Figure D-1
Well Locations where Nitrate Levels have been Recorded at 45 mg/l or Greater during the Period 1975 through 1987



Source: State Water Resources Control Board 1988.

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Figure D-2
Well Locations where Nitrate Levels have been Recorded within the Range of 20 through 44 mg/l during the Period 1975 through 1987

- **Climate:** High total rainfall, concentrated heavy rains, and mild temperatures lead to more leaching of nitrates.

- **Distance from the root zone to groundwater:** Less distance means a more immediate problem if nitrate levels begin to increase.

- **Potential impact:** The severity of nitrate leaching also differs based on such factors as population density and availability of an alternate water supply.

The DFA's FREP initial field activities have been directed at areas based on groundwater use, soil characteristics, crop type, irrigation practices, climate, distance to groundwater, and potential impact indicate the nitrate sensitivity of an area. In general, two regions of the state, the Central Coast valleys and parts of the east side of the Central Valley, fit the above criteria.

Mobility, Bioavailability, and Potential Toxicity of Plant Nutrients and Trace Elements in Biosolids

Several closely related issues are associated with the occurrence of nutrients, trace metals, and synthetic organic compounds in biosolids. These issues are analyzed in a fate and transport analysis, which evaluates what happens to these compounds in the soil; how their presence may affect agricultural productivity and sustainability; how they change and move through soil (to be taken up by plants and grazing animals and ultimately to enter the human food chain); and how they are removed from the immediate land application site as soil dust or eroded particles, or become dissolved and leave with surface runoff and groundwater flow.

Because all of the fate and transport mechanisms ultimately derive from the behavior of applied biosolids in the soil, this section of the EIR provides background information and an outline of some of the important chemical processes that occur in soils and influence plant uptake and the movement of compounds released from biosolids. A separate discussion is provided in Appendix E, "Public Health Technical Appendix", on uptake of biosolids-derived compounds, entry through the food chain, and related exposure mechanisms. Potential effects on soil productivity are discussed in the Chapter 4, "Land Productivity".

Most elements present in soil and taken up by plants (including nutrients and toxic metals) must be in a soluble form in the soil water (called solution phase) for recovery by plant roots and incorporation into the root mass or aboveground plant biomass. Once taken up, elements may be preferentially concentrated in various parts of the plant (e.g., leaf, petiole, flower, seed, fruit). If preferential concentrations greatly exceed background soil levels, the compounds are said to bioaccumulate. Elements contained in biosolids are released into the solution phase by microbial decomposition of organic matter containing the elements and/or by various physical and chemical processes. For discussion purposes, elements (with the exception of pathogens, which are discussed in Chapter 5, "Public Health", and Appendix E) contained in and released following biosolids application and subsequent decomposition can be placed in three broad groups:

- Major elements and plant nutrients, which include nitrogen, phosphorus, and potassium: These and other elements, such as calcium and magnesium, are generally more soluble, occur naturally in soils in relatively large amounts, and are required in moderate to large amounts for plant growth.
- Trace elements and heavy metals, which primarily occur in biosolids in small quantities and, when released, often form sparingly soluble reaction products: Some trace elements are required for plant growth, whereas other heavy metals may be toxic to plants.
- Potentially harmful synthetic organic compounds (SOCs), which typically are found in biosolids in very small amounts and are generally not taken up by plants: The principal concern with SOCs is ingestion of plants coated with dust from biosolids sources unusually high in SOCs, as well as direct biosoids ingestion by grazing animals.

Surface Water Runoff and Groundwater Leaching

Two of the key pathways identified in the Part 503 risk assessments were related to surface water runoff (Pathway #12) and the leaching of pollutants to groundwater (Pathway #14) from biosolids application sites. Surface water runoff from application sites can occur when rainfall exceeds the infiltration rate of the soil. Infiltration is influenced primarily by the permeability of the soil and the amount of water already stored in the soil. Runoff from application sites may cause erosion of sediments and transport of either dissolved or suspended contaminants to surface water bodies.

Leachate is water from either rainfall or irrigation that is transported through the soil. Some potential contaminants are soluble in water and may be transported in dissolved forms through the soils. Dissolved contaminants may then move through the soil and percolate to groundwater. Percolating groundwater may then move to surface water supplies or wells that provide drinking water. Complex biological, chemical, and physical processes govern how water moves through saturated and unsaturated porous materials.

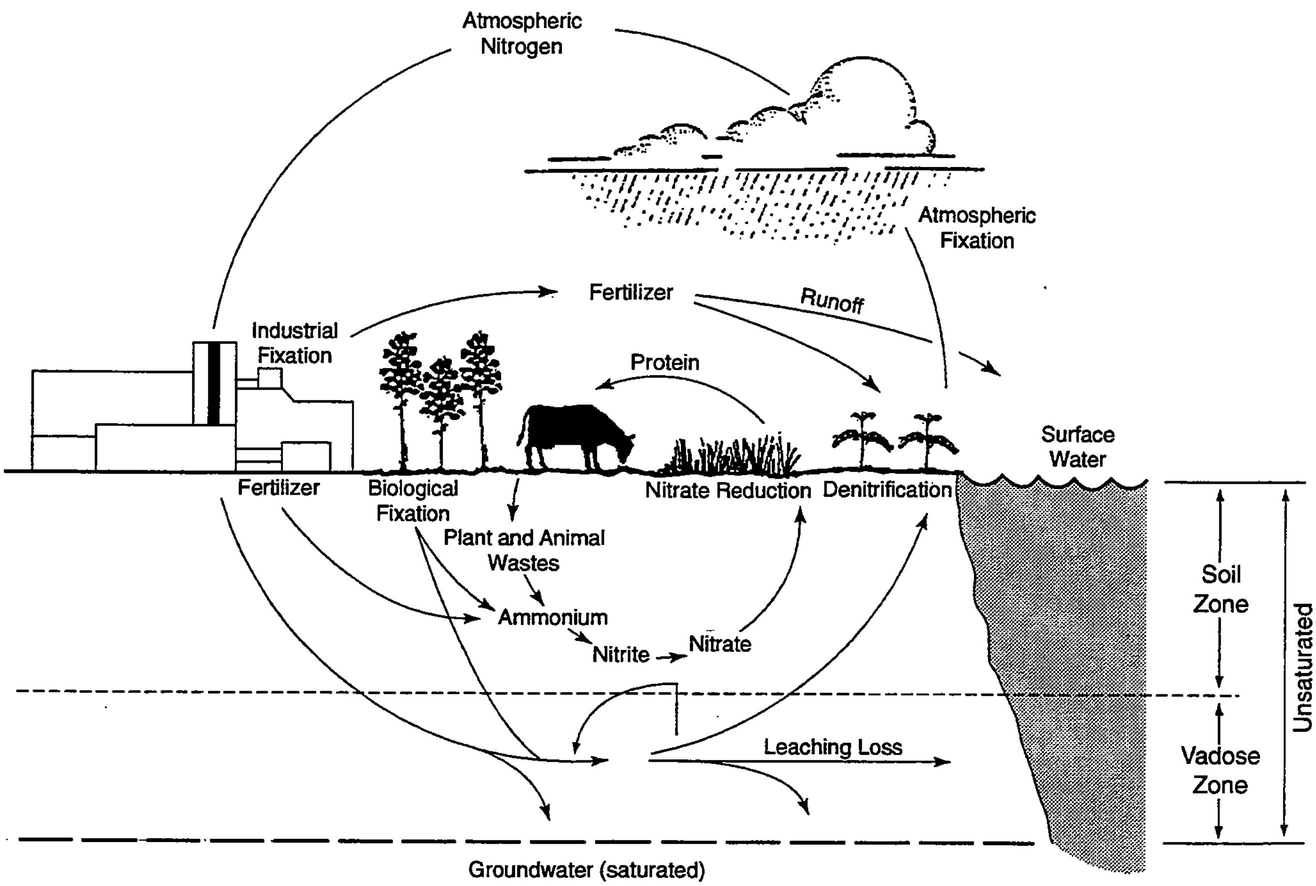
Definitions

It is convenient to characterize the presence of trace metals and nutrients in a soil (or soil amendment) as being readily available (generally soluble and easily taken up by plants or moveable through the soil); slowly available (requiring some combination of microbial or physical/chemical breakdown for release to the soil-water system); or relatively unavailable (requiring significant physical, chemical, and biochemical changes to become available for movement in the soil water and plant uptake). Most often, an element is present in the soil in all three relative states, transforming between the three states as soil chemistry and environmental conditions change over time. These processes are complex and quite variable in the soil environment and differ element by element. General terms used to describe these processes include transformation (change from one chemical form to another, often with different mobility, bioavailability, and toxicity), mobility (movement in the soil, generally with pore-water flow), and bioavailability (chemical form with respect to ability to be taken up by plant roots or soil macroorganisms or microorganisms). Soil mechanisms and processes that slow down or retard mobility and bioavailability are termed attenuation mechanisms. Phytotoxicity refers to compounds such as trace elements that are toxic to growing plants

Major Elements and Plant Nutrients (Nitrogen and Phosphorus) in the Soil Environment

Major plant nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium are typically present in moderate amounts in biosolids; however, their total content, mobility in the soil environment, and bioavailability can vary widely. In addition, biosolids can contain low to moderate levels of soluble salts. Some generalizations can be made with respect to their fertilizer value and other issues with respect to plant nutrient management, mobility, and bioavailability.

Biosolids applied to soils provide nitrogen and phosphorus in several forms. Nitrogen may be present as organic nitrogen, ammonium, nitrate and nitrite ions. Figure D-3 presents the nitrogen cycle and shows how nitrogen moves through the environment. The transformation processes of nitrogen are biologically and chemically controlled and include biological fixation, mineralization, nitrification, and denitrification. With respect to nitrogen content, biosolids are comparable to barnyard manure, providing a source of low-grade but slow- to moderate-release nitrogen. Biosolids contain 1%-6% total nitrogen on a dry-weight basis (National Academy of Sciences 1996). Commercial fertilizers contain 11%-82% total nitrogen. Organic forms of nitrogen generally predominate in biosolids and must be converted to inorganic forms to be utilized by plants, in a process called mineralization. Organic forms of nitrogen are not available to plants. A smaller percentage of the total nitrogen is in the form of gaseous ammonia or dissolved ammonium. Biosolids also typically contain a moderate amount of total and dissolved (i.e., plant-available) phosphorus. As with other trace elements, the transformations between gaseous, soluble inorganic, and less soluble residual or organic forms, and associated mobility in the environment, are complex.



Source: California State Water Resources Control Board 1994.

Figure D-3
The Nitrogen Cycle

The amount of organic and ammonia nitrogen in biosolids depends on the way biosolids are processed. Depending on site conditions, ammonium forms of nitrogen may be converted to ammonia gas and lost to the atmosphere, utilized by soil microorganisms, or converted to nitrates. Nitrate forms of nitrogen are the most biologically available but also the most mobile and present the greatest risk of groundwater contamination if released from biosolids at rates greater than the crops can uptake and utilize. Nitrates in biosolids are highly mobile in soil and have the potential to contaminate groundwater (Ocrtel 1995, Artiola and Pepper 1992) and are discussed in detail below.

Mineralization of Organic Nitrogen. Through mineralization, soil microorganisms convert organic forms of nitrogen to inorganic (mineral) forms—ammonium (NH_4) and nitrate (NO_3)—which are readily soluble in water and available for plant uptake. Nitrogen mineralization rates vary as a function of the organic nitrogen content of the biosolids, soil, and climatic conditions. Mineralization rates may also vary greatly for different sites, and mineralization rates need to be properly accounted for to determine agronomic rates of biosolids application. Nitrate is the dominant form in well-drained agricultural soils, whereas ammonium dominates where available nitrogen is at a premium and nitrification is low (University of Washington 1991). Mineralization of nitrogen can take from 1–5 years, depending on application rates and site conditions.

Immobilization and Soil Nitrogen Storage. Immobilization is the conversion of mineral forms of nitrogen to organic forms. Nitrogen can be stored in soil through binding to cation exchange sites, immobilization by soil micro-organisms, or as accumulated biomass. The ability to store nitrogen as ammonium on cation exchange sites is dependent upon the CEC level. Soil pH can also affect the CEC level: typically there are less exchange sites in more acidic soils. Biologic immobilization results in relatively long-term storage of nitrogen and generally occurs when the carbon to nitrogen ratio is greater than 30:1.

Volatilization of Ammonia. Ammonia and ammonium ions are added to the soil with biosolids or are produced during mineralization. Ammonia is a gas at normal temperatures and pressures, and the loss to the atmosphere can be great under certain conditions. Wind and temperature are major factors. Ammonia loss from biosolids or soils is also affected by pH. Under acidic conditions, nearly all of the ammonia is converted to the mineral form ammonium and the potential for gaseous loss is decreased. Above pH 7, more ammonia is present, increasing the potential for gaseous loss (University of Washington 1991). In acidic and neutral soils, NH_3 is converted to ammonium ions, which can then be sorbed by organic matter or clay particles, effectively taking it out of solution. The CEC level has been identified as one of the most important factors affecting ammonia volatilization (University of Washington 1991).

Nitrification and Nitrogen-Phosphorus Relationships. Nitrification is the microbiological transformation of ammonium ions to nitrate through a two-step, biologically catalyzed transformation process involving the formation from nitrite, and then conversion to nitrate.

Phosphorus is typically present in biosolids in low to moderate amounts and also requires mineralization of organic forms to biologically available forms. The relative proportions of nitrogen and phosphorus are as important in plant nutrition management as total amounts. If nitrogen is limiting in the soil to plant growth (relative to phosphorus), then the relative excess of phosphorus may accumulate in the soil and be subject to erosion and leaching, potentially affecting surface water and groundwater. This usually is not a significant concern in most native California agricultural soils, which are generally deficient in both phosphorus and nitrogen. In most California soils, phosphorus is tied up in various chemical forms and is not lost from the soil, except the phosphorus that is attached to soil particles entrained by runoff.

More often the case with biosolids in California, application rates are dictated by the nitrogen content of the biosolids relative to crop needs, thereby raising concern that overapplication of nitrogen could result in excess leaching to groundwater and potential degradation of water quality. In some cases, particularly with lime-stabilized biosolids, the phosphorus present in the biosolids and available phosphorus present in the soil can be chemically bound to the lime (functionally making the phosphorus unavailable for plant uptake), or additional microbial growth in soils may assimilate the phosphorus to accomplish organic matter decomposition. Consequently, induced phosphorus deficiency in plants can result, causing reduced plant growth or affecting quality and yield. Similarly, biosolids high in carbon but relatively low in nitrogen (i.e., a high carbon:nitrogen ratio) can induce nitrogen deficiency as soil microorganisms have insufficient available soil nitrogen to decompose the organic matter in the biosolids. The former (carbon:nitrogen-induced deficiency) is apparently a rare phenomenon in California, but deficiency induced by poor nitrogen:phosphorus balance can occur in lime-stabilized biosolids. For example, stalks of oat grass (grown for hay) can grow disproportionately long in response to high nitrogen while seed set is reduced or delayed. This can cause bend-over (“lodging”) of the grass stalks, making harvesting difficult and reducing yield and hay quality. If recognized early, such situations can be remedied by application of commercial fertilizers to bring the carbon:nitrogen or nitrogen: phosphorus ratio into balance with crop needs.

These problems usually can be easily avoided by testing the nitrogen, phosphorus, and potassium levels of the soil, measuring their concentrations in the biosolids, and adjusting biosolids additions and supplemental fertilizer applications to meet the agronomic needs of the crop. This involves setting application rates based on the nutrient most in abundance in the biosolids, not most limiting, and adding supplemental fertilizers when needed to make up for deficiencies.

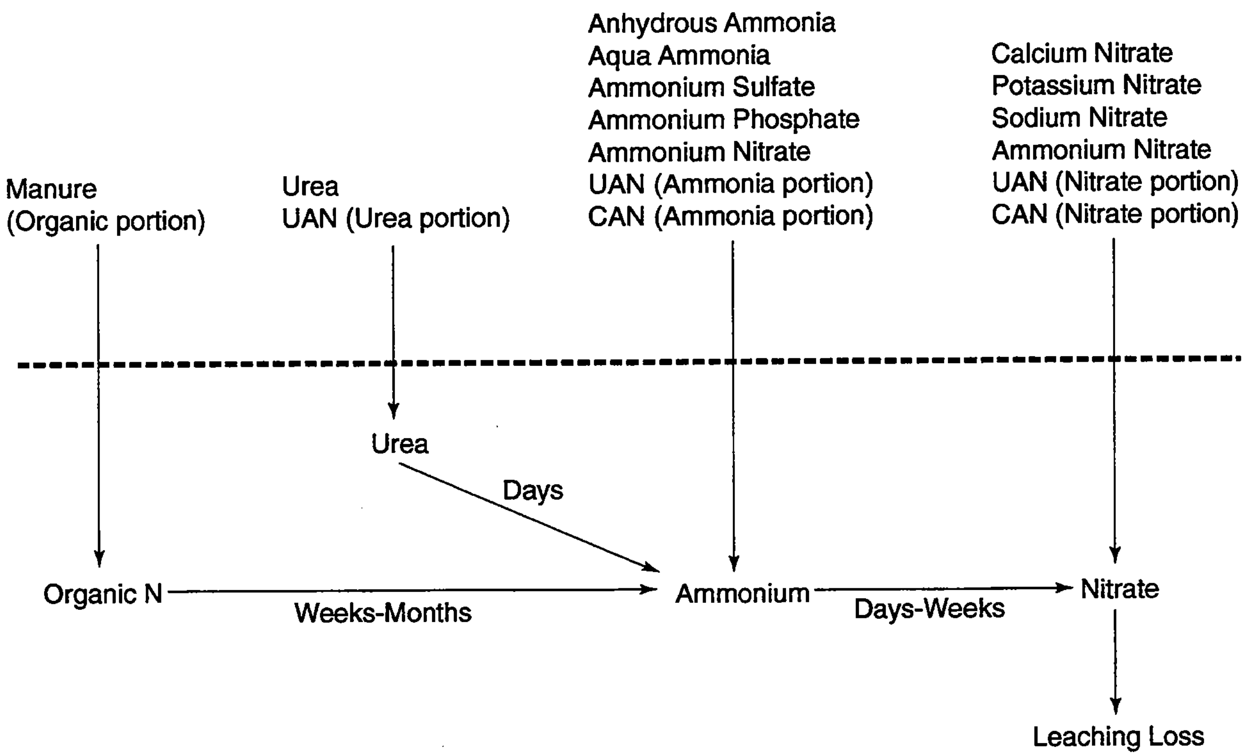
The GO and Part 503 regulations currently require application at agronomic rates for nitrogen but do not provide guidance for phosphorus. As previously indicated, it is possible but rare in California to create phosphorus pollution problems from biosolids high in phosphorus-to-nitrogen crop demand. It is also possible to create a nitrogen:phosphorus-induced deficiency problem in certain unusual conditions.

For non-exceptional quality biosolids, particularly from large municipal sources with heavy industry, annual biosolids application rates and the total long-term amount that can be land applied may be dictated by their trace element content, not by their nutrient load. This issue is discussed in the next section.

Transport Mechanisms of Nitrates in Groundwater. Nitrates are the form of nitrogen that presents a groundwater contamination risk. The biological and physical mechanisms that govern groundwater susceptibility to nitrate contamination are complex and highly variable. The three key processes that influence groundwater impairment from nitrates are related to 1) how the various forms of nitrogen contained in the biosolids react with the environment and are transformed to nitrate, 2) hydrologic features that transport nitrates through the soil to groundwater, and 3) how nitrates behave in the saturated portion of the aquifer and may reach municipal or domestic wells. Figure D-4 shows major fertilizer nitrogen sources and fertilizer nitrogen transformations in the soil (adapted from California Department of Food and Agriculture 1989).

The movement of nitrates from biosolids that are applied to the soil, through the unsaturated soil, to the nearest groundwater-bearing aquifer is governed primarily by the hydrology of the site and water infiltration. Nitrates are highly soluble and stable in most aqueous environments, making the dissolved fraction hard to remove from potential sources of drinking water. Both water and fertility management are necessary to prevent leaching of nitrates. Intentional overapplication of irrigation water is necessary to leach accumulated salts from the soil and maintain soil productivity. The total amount of nitrate leaching depends on the amount of nitrate dissolved in the soil-water profile and the volume of water percolating per unit time. The amount of nitrate is partially a function of the volume of nitrogen applied from all sources (fertilizer, manure, biosolids), and is thus subject to farm management practices.

Once out of the root zone, leachate containing nitrates will move into the unsaturated area above the water table. This unsaturated area is called the vadose zone (Figure D-3). The vadose zone may serve as a reservoir in which nitrates can accumulate. Further movement through the vadose zone is governed by complex flow and transport mechanisms. Travel time through the vadose zone may be many years (University of California 1995). Once the nitrates reach the saturated portion of the aquifer, they move with the prevailing groundwater flow. It is difficult to determine whether an observed level of nitrates in groundwater is a result of current or past operations. It is also difficult to quantify the level of nitrate contribution from the potential sources (agricultural, animal waste, septic, or wastewater sources) (California State Water Resources Control Board 1988, California Regional Water Quality Control Board 1994). Groundwater flow rates may vary greatly, and contaminated groundwater may take many years to reach municipal supply wells. The nitrate concentration in groundwater is influenced by freshwater recharge and dispersion, both of which may reduce contaminant



UAN - Urea Ammonium Nitrate
CAN - Calcium Ammonium Nitrate

Note: Time periods are for warm, moist soil.

Source: Adapted from California Department of Food and Agriculture 1989.

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Figure D-4
Major Fertilizer Nitrogen Sources and Fertilizer Nitrogen Transformations in the Soil

concentrations. Nitrates in groundwater do not impair agricultural beneficial uses of the water but may impair the suitability of the water for municipal and domestic uses. The assimilative capacity of a groundwater basin is a complex function of the recharge/discharge relationships and the mass loading of nitrogen from all sources.

Biostimulatory Nutrients Transport to Surface and Groundwater. Potential surface water quality impairment from biosolids applications are primarily related to potential runoff of biostimulatory substances that might impair the designated beneficial uses of water and result in violations of established water quality standards and objectives. Biostimulatory substances, primarily nitrogen and phosphorus, are typically found in low concentrations in aquatic systems. Eutrophication may result when additional nutrients are introduced into receiving waters. Eutrophication is the process by which nutrients increase biological productivity. Increased production can alter the biological system, potentially resulting in increased biomass production and resultant reductions in dissolved oxygen.

The effects of land application of liquid or dewatered biosolids on runoff water quality have received limited examination, in part because of the conservatism built into EPA's Part 503 guidelines, which require buffers and other management practices that restrict runoff and transport of potential contaminants (Northwest Biosolids Management Association 1998). Despite the limited amount of research specifically directed at liquid or dewatered biosolids applications, there are numerous studies evaluating nutrient runoff from agricultural lands, rangelands, and silvicultural areas where other biosolids or sources of nitrogen and phosphorus have been investigated. Nitrogen and phosphorus must be in mobile, dissolved forms for direct transport in surface water. Inorganic forms may be transported along with other sediments. There is a general consensus that application of biosolids or chemical fertilizer to no-till agricultural systems is a more effective means of limiting runoff of nutrients and sediment than application to conventional tillage (Breuggeman and Mostaghimi 1993, Mostaghimi et al. 1992, Northwest Biosolids Management Association 1998). Times of maximum seasonal precipitation have been strongly correlated to elevated nitrate levels in surface water and groundwater (Tindall 1994). Biosolids application techniques (surface application or incorporation into the soil, till or no till), total application rates, seasonal weather patterns, ambient soil moisture, and the duration and intensity of rainfall all influence the potential for runoff to mobilize nutrients in biosolids (Northwest Biosolids Management Association 1998).

Liquid biosolids have far greater concentrations of the mobile mineral forms of N and P than do the dewatered biosolids which are regulated by the GO. Studies related to the application of liquid biosolids to a watershed have demonstrated that there was little to no impact on stream water quality with respect to N and P levels. It is suggested that the application of dewatered biosolids will likely have no significant impact on the quality of water emanating from watersheds where dewatered biosolids are applied. This statement is qualified by the fact that there is a lack of peer-reviewed studies on the subject of water quality runoff covering an extensive range of conditions under which biosolids might be applied (Northwest Biosolids Management Association 1998).

Phosphorus is present in both organic and inorganic forms in biosolids, typically at concentrations of 0.8%–6.1%. Inorganic forms of phosphorus are quite insoluble and phosphorus tends to concentrate in the organic and inorganic solid phases. The amount of phosphorus applied is more than sufficient to meet the needs of the crop in areas where biosolids are applied to meet nitrogen requirements. At the appropriate application rate for nitrogen, available phosphorus may exceed the levels needed for crop production. High levels could increase the risk of surface water contamination if runoff is allowed. Based on long-term evaluations of treated biosolids over periods ranging from 9 to 23 years, the Water Environment Federation (1994) has recommended that soil phosphorus levels be monitored in areas where biosolids applications are used continuously over time, and that biosolids application rates may need to be determined by crop phosphorus levels rather than to meet the nitrogen needs of crops (National Academy of Sciences 1996).

Other essential plant nutrients and inorganic constituents are found in biosolids, including calcium, iron, magnesium, manganese, potassium, sodium, and zinc. Where biosolids are applied according to agronomic rates for nitrogen, most of these essential nutrients are usually present in amounts adequate to meet the needs of the crop (National Academy of Sciences 1996). No studies were found that indicated problems with excess runoff or leaching of other inorganic constituents found in biosolids. The concentration of other salts or minerals that could increase the total dissolved solids concentration in runoff or leachate has not been identified as a problem for contaminant runoff or leaching to groundwater. This is because most of the dissolved minerals are leached from the biosolids during wastewater treatment and sludge dewatering operations.

Trace Elements and Heavy Metals

Trace Elements and Heavy Metals in the Soil Environment.

The terms *trace metal* and *trace element* refer to chemical elements normally present in the environment in very low concentrations. Typically, elements that are present in the soil in the dissolved phase at concentrations less than 0.01 microgram per milliliter are considered to be trace elements. Major elements or plant nutrients usually are present in the soil solution phase at concentrations orders of magnitude higher. Heavy metals are defined as trace elements that have densities greater than 5.0 milligrams per cubic centimeter.

In small quantities, many elements are essential to plant growth. These include fluoride, silicon, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, silicon, selenium, molybdenum, tin, and boron. At higher concentrations, some of these elements may become toxic to plants or accumulate in plants at levels that are toxic to animals that feed on them. In some cases, the range in concentrations between deficiency and toxicity is narrow, such as with boron. In several cases, there is no known biological necessity for a trace metal and its occurrence in small quantities in the soil solution may be harmful to plants. Lead, cadmium, and arsenic are examples of this effect. In other instances, such as with molybdenum, there is little or no plant toxicity at elevated soil levels, but grazing animals can be adversely affected by high levels in plant forage. Plants can vary widely in their sensitivity to trace element concentrations in the deficiency or toxicity range, in their capability to take up trace elements, and in their ability to avoid uptake even at high soil solution concentrations. Some, but not all, of the trace elements that can be present in biosolids in elevated concentrations are regulated in EPA's Part 503 regulations.

Trace metals may behave differently compared to more common soluble salts and plant nutrients in soils. Unlike soluble salts, most metallic compounds are not readily soluble in water or very mobile in the soil, except at low pH levels (as in strongly acidic soils). Because of their affinity to soil particles, including clay and organic colloids, carbonates, and iron complexes, trace metals are often retained in the soil and normally do not move readily with soil water. Therefore, most metals added to soils from irrigation water, reclaimed water, fertilizers, or organic additions such as biosolids may readily accumulate in surface layers and remain there, relatively biologically unavailable and immobile.

There are, however, important exceptions to this: arsenic, molybdenum, and cadmium in particular can be mobile in non-acidic soils and, under certain conditions, can accumulate in bioavailable forms and be potentially toxic in low soil-solution concentrations. Boron behaves differently in the soil than other trace elements, in that it is somewhat soluble and mobile. Plants vary widely in their boron phytotoxicity. Boron is naturally present in excessive concentrations in a small proportion of California soils. Although the total metal concentration is easy to measure in soils and biosolids, it is often a poor indicator of the mobility or bioavailable quantity of the metal in the soil when an understanding is lacking of the chemistry of the particular soil to which biosolids containing metals have been added.

The amount of accumulation of metals in soil (soil loading) is a function of the concentration of metals in the irrigation water, reclaimed water or biosolids, and the amount of material applied. The multiplication of concentration times annual application rate is termed the annual loading rate; cumulative loading refers to summation of loading over time. These are usually given in terms of pounds of trace metals added per acre or, in metric terms, kilograms per hectare. It is important to note that loading refers to the total amount added to the soil in all forms, and not the final soil concentration.

Total loading rates also do not distinguish between plant-available and mobile forms of metals in the soil solution. Aside from those originating from cities with extensive heavy industry, most biosolids contain low concentrations of trace metals, relative to levels that can accumulate and adversely affect soil productivity and agricultural sustainability under normal California soil conditions and loading rates. The low mobility of biosolids derived metals in typical soil environments has been demonstrated in research conducted by Camobreco et al. (1996) and Dowdy et al. (1991). However, some scientists remain cautious regarding the potential for adverse soil quality and health effects from poorly designed and poorly managed biosolids land application programs, particularly for non-exceptional quality biosolids or where unusual soil conditions and cropping patterns occur (Cornell Waste Management Institute 1999). The current GO and Part 503 regulations do not require specific consideration of bioavailable metals concentrations, irrigation and cropping practices that can affect bioavailability, or bioaccumulation factors and mobility when determining biosolids application rates.

Movement of water containing soluble trace elements and nutrients through the soil, and hence bioavailability, is influenced by a variety of physical processes and chemical reactions that determine the capacity of a natural soil body to immobilize metals, nutrients, and trace elements. The mechanisms of removal and movement are complex and depend on both the source and characteristics of the trace elements, the physical and chemical properties of the soil, and the rate of water movement through the soil.

Crops may also vary widely in their ability to uptake and bioaccumulate trace elements and in their sensitivity to concentrations in deficiency or phytotoxicity ranges. At any time, the concentrations of the major elements and trace metals in the solution phase of the soil-water-plant system are governed by various reactions, such as acid-base equilibria, complexation with organic and inorganic lignins and organic factions forming chelated compounds, precipitation and dissolution of solids of oxides and carbonates, and ion-exchange-adsorption on clay minerals. The issue is so complex that entire textbooks are written on the environmental chemistry of soils and the transformation and movement of organic and inorganic compounds in soils (for example, see McBride 1984, Dragun 1988, Davies 1980, Kabata-Pendias 1984).

The concentrations of major and minor elements in the soil-water solution are controlled by the progression in equilibrium in the solid and solution phases between unavailable and readily bioavailable forms, the rate at which these reactions occur, the rate of biological uptake by plants, and the loss from the system by groundwater flow. Soil clay content, CEC, organic matter content, oxidation/reduction state, and pH all influence the mobility and bioavailability of metals/nutrients in the soil to some degree.

The solubility (and hence mobility and bioavailability) of cadmium, copper, nickel, zinc, and chromium compounds is significantly pH dependent. The solubility of these metals typically increases as pH levels decline (i.e., become more acidic). These metals are associated with iron and manganese hydrous oxide compounds whose solubility increases with decreasing soil pH. The hydrous oxide or sulfide compounds are also more soluble under reducing conditions (i.e., when losing electrons caused by prolonged anaerobic conditions). As a result, poorly drained, acidic conditions that occur in some California soils tend to favor mobilization of metals, whereas well drained, non-sandy, basic (alkaline) to slightly acidic soils tend to immobilize most cationic metals. Lead generally has limited mobility in the soil. In slightly acidic, non-calcareous soils, lead generally is not bioavailable and tends to precipitate as lead hydroxides or lead polymorphites; consequently, it does not readily reach groundwater. Maintaining suitable soil pH levels, drainage, and organic matter content thus becomes extremely important in managing lands to which biosolids have been applied. Because metal mobility varies with pH and the particular metal species, it is important to characterize and understand biosolids, soil chemistry, soil hydrology, and crop conditions to ensure sound biosolids application management.

The amount of finely divided, stable organic matter (humic and fulvic acids) in the soil can also greatly affect the mobility of metals in the soils by forming insoluble or slightly soluble complexes. Biosolids provide a rich source of these substances. Other reactions that immobilize metals include adsorption onto clay surfaces and ion exchange, particularly of divalent metallic cations. The organic matter- and clay-rich valley bottom land, basin, and low terrace soils in many areas of California should strongly immobilize metals contained in biosolids through organic complexing and cation exchange. Of greater concern is sandy, acidic soils with low organic matter content, in which metals are easily transformed to be readily bioavailable and in which water moves freely with little soil interaction. These soil conditions are somewhat rare in California, but they occur on recent sandy alluvial fan soils associated with the granitic foothills of the southern San Joaquin Valley, in some high mountain valleys, and in parts of San Diego and Monterey Counties. The soils of valley margin foothills, which are often acidic and have low organic matter content, can also be difficult to manage for biosolids application. Areas of shallow perched groundwater may also raise management concerns.

Because of the complexity of all the possible interactions of nutrients and trace elements in the soil-water-plant system, it is difficult to accurately predict element concentrations in plants from a biosolids source as it leaches through the root zone, is taken up by plants, and/or moves through the shallow groundwater system. This difficulty is compounded when water movement through the soil and subsequent deep percolation to groundwater or to streams must also be considered. Although scientists have developed several numerical models that can quantitatively estimate movement of major nutrients and some metals in the soil-water solution, plant uptake, and discharge to shallow groundwater, these are approximations at best. Quantitative analysis of particular metal types requires consideration of site-specific characteristics of soils, water movement, climate, and crop type. Given the wide range of these conditions in California, the use of numerical models is not practical for the purposes of this EIR. Broad assumptions of soil-crop factors were used in evaluating potential plant uptake of metals and in formulating the Part 503 sludge regulations, some of which have been questioned (Cornell Waste Management Institute 1999).

Table D-6 provides general information on the characteristics of major and trace elements, including factors influencing bioavailability and plant toxicity or phytotoxicity. Table D-7 shows various physical and chemical processes in the soil that have important effects on the mobility and bioavailability of metals. Included in the table are mean K_d values (a measure of the mobility or adsorption propensity of the metal while moving with groundwater through porous media) determined for typical soils for various elements, and

Table D-6
Occurrence, Biological Function and Toxicity of Trace Metals in Soils

Trace Metal	Common Range in California Bio Solids[a] (*mg/kg*)	Common Range in Soils[b] (*Total mg/kg)*	A Typical Soil Concentration[c] (*Total mg/kg)*	Biological Function[d]	Mammalian Toxicity[d]	Phytotoxicity[d]	Impact on Crop[e] (*mg/kg*)	Cumulative Pollutant Loading Rate Limits (*kg/ha*)[f]	Title 22 Toxic Limits[g] (*mg/kg*)
Arsenic		0.1 - 40 3.6 - 8.8	6	None known in animals. Constituent of phospholipid in algae and fungi	High	Medium-High (5-20)	Not a required element for plant growth	41	500
Boron		2 - 55	10	Essential to plant. Phosphogluconate	Low	Medium-High (50-200)	Required, wide species differences	Not regulated	Not listed
Cadmium		0.01 - 1.1	0.06	None known	High Cumulative poison	Medium-High (5-30)	Not required, toxic to plants	39	100
Chromium		20 - 85	40	May be involved in sugar metabolism in mammals	High (Cr^{6+}) Medium (Cr^{3+})	Medium-High (20-100)	Not required, low plant toxicity	Not regulated	2,500
Copper		14 - 29	20	Essential to all organisms, cofactor in redox enzymes, 0_2 transport pigments	Medium	Medium (30-300)	Required 2-4 mg/kg; toxic>20 mg/kg in plant tissue	1,500	2,500
Lead		0.2 - 200	10	None Known	High Cumulative poison	High (1-3)	Low plant toxicity	300	500

Table D-6. Continued

Trace Metal	Common Range in California Bio Solids[a] (*mg/kg*)	Common Range in Soils[b] (*Total mg/kg*)	A Typical Soil Concentration[c] (*Total mg/kg*)	Biological Function[d]	Mammalian Toxicity[d]	Phytotoxicity[d]	Impact on Crop[e] (*mg/kg*)	Cumulative Pollutant Loading Rate Limits (*kg/ha*)[f]	Title 22 Toxic Limits[g] (*mg/kg*)
Mercury		0.01 - 0.08	--	None Known	High (soluble or volatile forms). Cumulative poison	Medium (10-50)	High plant toxicity	17	20
Molybdenum		0.35 - 5.8	2	Essential to all organisms, enzyme cofactor in N^2 fixation, NO_3 reduction	Medium	Medium-High (10-100) Bio-accumulative	Required; at <0.1 mg/kg in plant tissue	Not regulated	3,500
Nickel		10 - 1,000	40	None known in mammals. May be essential to plants. Found in urease enzyme	Medium	Medium-High (5-30) Bio-accumulative	Not required toxic >50 mg/kg in plant tissue	420	2,000
Selenium		0.19 - 1.05	0.5	Essential to mammals and some plants	High	High (5-10)	Toxic >50 mg/kg	100	100
Silver		0.1-5.0	--	None known	High	Low-Medium (100-400)	--	Not regulated	500
Zinc		10-300	50	Essential to all organisms. Cofactor in numerous enzymes	Low-Medium		Required: toxic >200 mg/kg in plant tissue	2,800	5,000

Sources:

a

b Compiled from McBride 1994, Drugan 1988, Pettygrove 1984.

C Pettygrove et al July 1984.

D Abstracted from McBride 1994

e Abstracted from McBride 1994.

f EPA 503 Rules.

g California Title 22 Limits.

Table D-7
Trace Element Mobility and
Soil Transformation Mechanisms

Trace Element	Mean K_{ds}	Mobility at Various Soil pH Levels: Strongly Acid pH <5.5	Moderately Acid pH 5.5 to 7.0	Alkaline pH >7.0	Reacts to Less Bio-Available Form With: Fe/Mn Oxides	Organic Matter	Other	Primary Attenuation Mechanism
Arsenic	1.2	Medium-Low	Medium	Medium-High	Yes	--	sulfide, clays	precipitation (iron), specific adsorption
Boron	--	Medium-Low	High	Medium-High	--	--	calcium	caborate precipitation
Cadmium	1.9	Medium	Medium-High	Medium	No	--	reducing conditions	precipitation (hydroxides, carbonates, sulfides), specific adsorption
Chromium	7.7	Very Low	Very Low	Very Low	Yes	--	--	precipitation
Copper	3.1	High	Medium to Low	Very Low	Yes	Yes	sulfide, sulfate clay adsorption, carbonate, phosphate, reducing conditions	precipitation (hydroxides, carbonates, sulfides), specific adsorption
Lead	4.6	Low	Low	Low	--	--	reducing conditions	precipitation (hydroxides, carbonates, sulfides), specific adsorption
Mercury	--	Medium	Low	Low	Yes	--	sulfide, reduced conditions	adsorption at high pH
Molybden um	--	Low	Medium-High	High	Yes	Yes	n____erystalime aluminosilicates	clays at low pH
Nickel	--	High	Medium to Low	Very Low	Yes	Yes	sulfide adsorption, silicate minerals	precipitation (hydroxides, carbonates, sulfides),

Table D-7. Continued

Trace Element	Mean K_{ds}	Mobility at Various Soil pH Levels			Reacts to Less Bio-Available Form With			Primary Attenuation Mechanism
		Strongly Acid pH <5.5	Moderately Acid pH 5.5 to 7.0	Alkaline pH >7.0	Fe/Mn Oxides	Organic Matter	Other	
Selenium	1.0	High	High	High to High	Yes	Yes	reducing conditions, absorption	precipitation (iron), specific adsorption
Silver	4.7	High	Medium to Low	Very Low	Yes	Yes	reducing conditions, sulfide	cation exchange
Zinc	2.8	High	High to Medium	Low to Very Low	Yes	Yes	sulfide, precipitation by carbonate	precipitation (hydroxides, carbonates, sulfides), specific adsorption

Sources: Dragun 1998, McBride 1994, Baes and Sharp 1983, Kabate-Pendias 1992, and Selim and Amacher 1997.

Note: K_{ds} is a coefficient or measure of the mobility or adsorption propensity of a metal while moving with water through porous media, such as a soil.

conducted for only those trace metals that were identified as having potential to be present in biosolids at sufficient concentrations to cause environmental toxicity or other impairment. Of the original list of approximately 200 pollutants evaluated for possible consideration in the Part 503 regulations, the risk assessments for surface water and groundwater pathways were conducted for seven trace metals (U.S. Environmental Protection Agency 1992). All other trace metals were either not detected in the sewage sludges tested during the 1990 National Sewage Sludge Survey (U.S. Environmental Protection Agency 1990) or were detected at sufficiently low concentrations to warrant no further consideration. Of the 14 pathways evaluated for the Part 503 regulations, neither the surface water or the groundwater pathway was found to be limiting to trace metal concentration limits or cumulative loading rates for land application of biosolids.

Some of the factors and assumptions used during the Part 503 development process for setting limits on trace metals are controversial. The risk assessments conducted for the groundwater pathway are a source of controversy among researchers and respondents to the scoping notice for this EIR. The primary arguments for considering inclusion of limits to organic compounds in the Part 503 regulations include the following: (1) elimination process was arbitrary, (2) lack of monitoring requirements results in not having information on which to base application decisions, (3) may not consider risks associated with specific compounds that lack supporting research data, and (4) groundwater dilution factors may have been too large (Cornell Waste Management Institute 1999).

Based on the recent 1998 California Association of Sanitary Agencies (CASA) survey of trace metal concentrations in sewage sludges from California (California Association of Sanitation Agencies 1999), average concentrations and variability are lower than the 1990 National Sewage Sludge Survey (NSSS) data (U.S. Environmental Protection Agency 1990). Average concentrations of cadmium, copper, lead, nickel, and zinc for the 1998 CASA data range from 25% to 50% of the 1990 national averages; 1998 CASA averages for arsenic, mercury, and molybdenum are generally similar to the national estimates. Selenium is the only trace metal that has higher average concentrations in the 1998 CASA data than in the 1990 NSSS results. Maximum reported concentrations of copper, mercury, and selenium are the only measurements in the 1998 CASA survey data that exceed the ceiling concentration limits under the discharge prohibitions of the proposed GO regulation.

Synthetic Organic Compounds

Synthetic Organic Compounds in the Soil Environment. Many SOCs used in industrial, commercial, and household applications can be conveyed to wastewater treatment plants through the municipal wastewater collection and treatment process, and therefore they can be present in biosolids. As with nutrients and trace elements, the character of the biosolids with respect to SOC content is a function of the type of business and industry within the wastewater treatment service area, any onsite pretreatment conditions, and the effectiveness of the wastewater treatment process.

Many organic compounds either are volatile (and are lost during the treatment process) or readily biodegrade in the treatment process, which is designed and managed to foster microbial decomposition. Other volatile compounds are quickly lost to the atmosphere following biosolids incorporation in the soil. Because of this, the possible presence of volatile organic compounds in biosolids has generally not been of great concern to regulators and the environmental community.

However, other non-volatile or semi-volatile organic compounds (SVOCs) generally occur in low amounts in municipal biosolids. These include plastic-like compounds (phthalates), pesticides, phenols, detergent additives, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyl compounds (PCBs), and the group of chlorinated dibenzo-para-dioxin and chlorinated dibenzo-furan compounds that are often cumulatively referred to as dioxins. Currently, the Part 503 regulations do not contain minimum standards or require testing of biosolids for SOCs; however, the proposed GO monitoring program would require testing of biosolids for PCBs and SVOCs. Upper limits are set by state and federal general hazardous materials rules and regulations, with control relying on local municipalities enforcing source inspection and pretreatment provisions associated with their wastewater discharge permits. Toxic chemicals such as DDT, chlordane, aldrin, dieldrin, benzo(e)pyrene, and lindane are known to cause cancer, and other compounds are known to be teratogenic (e.g., dioxin, 2,4,5-trichlorphenol, and pentachlorophenol). Consequently, many of the SOCs have been prohibited from use or manufacture in the United States.

Much less is known about SOCs with respect to soil accumulation, plant uptake, and concentration mechanisms in soils than is known about trace elements. The knowledge base is much greater with regard to the attenuation, degradation, and mobility of volatile compounds, pesticides, and PAHs in the soil. It is generally understood that the primary exposure pathways for organic compounds are through migration to drinking water sources or as residues and soil dust that accumulate on plant leaves, rather than as direct plant uptake. Direct ingestion of soil containing biosolids or ingestion by grazing animals as dust on plant parts is another area of concern. There are human health risk factors; however, as with phytotoxic trace elements, accumulation of SOCs in soils at levels that make the soils unusable for crop or livestock production can be considered a rather drastic agricultural soil productivity impact. This issue is reviewed in Chapter 4, “Land Productivity”.

Synthetic Organic Compounds in the Aquatic Environment.

Biosolids can contain various organic compounds that are removed from the liquid waste stream during the wastewater treatment process. More than 100 EPA-designated priority pollutant organic compounds are regulated through various federal and state drinking water standards, ambient surface water quality criteria, and hazardous waste laws. Most of the priority pollutant organic compounds are generally not detected in biosolids or are present at very low levels (U.S. Environmental Protection Agency 1990).

It is generally recognized that transport of organic compounds from the solid to the liquid phase in the soil environment is limited for most constituents (U.S. Environmental Protection Agency 1992, Chaney 1990). Demirjian et al. (1987) evaluated the fate of organic compounds in soil from biosolids application and showed that organic compounds were degraded in the soil or adsorbed in the surface layer. At an application rate of 100 tons per acre, most compounds degraded considerably during one irrigation season. At less than 25 tons per acre, most compounds degraded to less than 50% of initial concentration. The authors concluded that their experiment represented severe conditions for land application because of the sandy soils and heavy irrigation requirement and, therefore, nutrients and heavy metals would be the limiting factors in determination of application rate under average soil conditions. Alexander (1995) showed that the binding effect that "locks" toxins in the soil becomes more pronounced the longer the pollutant remains in soil. The higher the organic matter, the greater the binding effect. The report indicates that disappearance of appreciable amounts of insecticides from the field was not a result of leaching because all are extensively sorbed and little vertical movement has been detected, even after many years. If a chemical persists and remains in contact with particulate matter for some time, it becomes increasingly resistant to extraction by many solvents. Rappe et al. (1997) reported that dioxins have extremely low solubility and are unlikely to leach from soil to groundwater.

Part 503 Risk Assessments of Synthetic Organic Compounds for Surface Water and Groundwater Pathways. Toxic organic compounds were included in the original pollutant screening and risk assessments conducted during development of the Part 503 regulations for land application of biosolids. Of the original list of approximately 200 pollutants evaluated for possible consideration in the Part 503 regulations, the risk assessments for surface water (Pathway #12) and groundwater (Pathway #14) were conducted for 10 priority pollutant organic compounds (U.S. Environmental Protection Agency 1992). All other organic compounds were not detected in the tested sewage sludges or were detected at sufficiently low concentrations to warrant no further consideration. Of the 14 pathways evaluated for the Part 503 regulations, the groundwater pathway was not found to be limiting for the concentration limits or cumulative loading rates of any organic compounds resulting from land application of biosolids. The surface water pathway of humans eating fish that accumulate pollutants in surface runoff was the limiting pathway for setting limits on DDT/DDE compounds.

Upon completion of the EPA risk assessments for organic compounds, EPA concluded that regulations for organic compounds were not required for the final Part 503 regulations because they met at least one of the following criteria: (1) the pollutant was banned from use, has restricted uses, or is not manufactured in the United States; (2) it was detected in less than 5% of the sludges tested for the 1990 National Sewage Sludge Survey; or (3) the 1-in-10,000 cancer risk limit was less than the 99% maximum probable concentration based on 1990 NSSS data. Limits were not set for DDT/DDE compounds because they are excluded from all of EPA's screening criteria. Several organic compounds were deferred for future consideration and evaluation for round two of the rule development, when more data would be available. The organic compounds of interest for future consideration included PCBs and dioxin. There is also research being conducted on various other aromatic surfactants (e.g., linear alkylbenzene sulphonates and ethoxylates) that may have hormone-mimicking properties; however, very little is known about their role in transport from biosolids application sites (Krogman 1997, Clapp et al. 1994).

Some of the factors and assumptions used during the Part 503 development process for setting limits on toxic organic compounds are controversial. The elimination and deferment of Part 503 limits for organic compounds is a source of controversy among researchers and respondents to the scoping notice for this EIR. The primary arguments for considering inclusion of limits to organic compounds in the Part 503 regulations were identified above (see "Part 503 Risk Assessments of Trace Metals for Surface and Groundwater Pathways"). Comments received during the scoping process indicated a concern that the Part 503 risk assessments may not accurately reflect environmental conditions specific to California or account for risks from new organic compounds such as pharmaceuticals. There is also general concern regarding the potential oversight of the Part 503 regulations in not accounting for synergistic or combined risks from exposure to multiple constituents that may be present in biosolids. EPA contends that the risk assessment process was based on conservative assumptions and no scientific data are present that would invalidate the results of the risk assessments (U.S. Environmental Protection Agency 1995).

Regulatory Setting

Key Policies, Laws, Programs

Water Quality Regulations and Permits.

Numerous laws, ordinances, and guidelines are administered by local, state, and federal agencies to limit the discharge of pollutants to the environment; maintain surface water and groundwater quality at existing levels; and protect beneficial uses such as municipal, industrial, and agricultural water supply, recreation, and fish and wildlife habitat. The California State Water Resources Control Board (SWRCB) establishes water quality control policies in California in accordance with the Porter-Cologne Water Quality Control Act and the federal Clean Water Act and implements those policies through nine individual RWQCB offices. Federal, state, and local water quality regulations are applicable to any chemical constituent contained in biosolids or any activities that would occur as a result of land application of biosolids. The nine regions were initially established according to regions with similar and unique hydrologic and water quality characteristics. Figure 1-1 shows the names and boundaries of the nine regional boards.

Each RWQCB has primary responsibility for designating the beneficial uses of water bodies within the regions, establishing water quality objectives for protection of those uses, and issuing permits and conducting enforcement activities. Beneficial uses are those uses of the water resource for which numerical and narrative water quality objectives are established to prevent water quality impairment. Water quality objectives and associated narrative and numerical water quality objectives are established in a Basin Plan for each region that is updated through a triennial review process. The principal permitting processes administered by the RWQCBs for water quality protection include issuance of waste discharge requirements (WDRs) for discharge of waste to land and water, and permits for the National Pollutant Discharge Elimination System (NPDES) in accordance with the federal Clean Water Act. WDRs and NPDES permits issued to waste dischargers impose discharge restrictions and pollutant limits, that take into consideration applicable state and federal water quality criteria for surface water, groundwater, and drinking water. The permit processes must also consider the state anti-degradation policy that is intended to maintain high quality waters by setting criteria that must be met before a discharge is allowed that would reduce water quality and yet still maintain beneficial uses.

Numerical Water Quality Criteria. Potential effects of waste discharges may be evaluated, undergo regulatory review by other resource agencies, or have permits issued that are based on a several categories of state and federal water quality criteria. Applicable water quality criteria include Basin Plan water quality objectives for surface water and groundwater, state and federal ambient surface water quality criteria, and state and federal drinking water standards. The RWQCBs are required to include effluent limitations on toxic priority pollutants in WDRs and NPDES permits issued for wastewater discharges to surface waters when the discharge may cause the surface water to exceed established priority pollutant standards. The regulated priority pollutants include approximately 130 trace metal and organic compounds that are known to be toxic to living organisms when present in water at sufficient concentrations.

Regulations pertaining to priority pollutants have been developed over the years in four main regulations, including narrative requirements in the Clean Water Act, the National Toxics Rule (NTR), the now-defunct Inland Surface Waters Plan/Enclosed Bays and Estuaries Plan (ISWP/EBEP), and the recently proposed California Toxics Rule (CTR). The proposed CTR was developed in accordance with Section 303(c)(2)(B) of the Clean Water Act (Federal Register Vol. 62, No. 150 - August 5, 1997) to fill the gap in regulation created by the legal overturn of the ISWP. The SWRCB subsequently issued a Draft Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California and Accompanying Functional Equivalent Document (California State Water Resources Control Board 1997) that identifies the proposed rules for implementation of the CTR criteria as a new ISWP. Following adoption of the CTR and/or another form of ISWP, wastewater discharges and NPDES-permitted facilities will be required to comply with the new standards for priority pollutants. The criteria were developed to protect against acute and chronic toxicity of aquatic organisms and humans from ingestion of water or organisms in contact with the water. By definition, the criteria represent "the highest concentration of a substance in water which does not present a significant risk to the aquatic organisms in the water and their uses". Under the criteria, toxicity in aquatic organisms is defined as mortality or reduction in growth; toxicity in humans is defined as an increased risk of disease or cancer. The criteria also provide protection from bioaccumulation in aquatic organisms. Bioaccumulation is a process whereby, through absorption or ingestion, the constituents accumulate in the tissues of aquatic plants or animals over time.

Drinking water standards, established by the DHS under Title 22, Division 4, Chapter 15 - Domestic Water Quality and Monitoring, are applicable to groundwater and surface water. EPA develops similar standards under the federal Safe Drinking Water Act. Both sets of laws contain MCLs that are based on a 1-in-1-million (10^{-6}) incremental risk of cancer from ingestion of carcinogenic compounds and threshold toxicity levels for noncarcinogens. The MCLs are also based on technological and economic factors of the feasibility of achieving and monitoring for the pollutants in a drinking water supply. Secondary MCLs are established for welfare considerations such as taste and odor control and laundry staining. The MCLs apply to the quality of the water after it has entered a distribution system and do not apply to the quality of the untreated source water. The standards apply to the source water only when specifically established in the basin plan by the RWQCB.

National Pollutant Discharge Elimination System Permits.
Wastewater treatment plants (WWTPs) that discharge to surface waters are regulated through the NPDES permitting process, which is mandated under the Clean Water Act (Code of Federal Regulations [CFR], Title 40). The NPDES permit system is divided into separate programs and regulations for point-source discharges, such as industrial facilities and WWTPs, and nonpoint sources such as urban stormwater runoff from larger municipalities and storm water runoff from general construction and industrial activities. The NPDES permit process for WWTPs typically involves the imposition of standards on the effluent and receiving water body for various chemical, physical, and biological parameters (e.g., flow, temperature, pH, biochemical oxygen demand [BOD], dissolved oxygen [DO], total coliform bacteria, suspended and settleable matter, turbidity, residual chlorine, ammonia, or other compounds of specific concern for a given receiving water). NPDES permits focus mainly on the liquid discharge, whereas WDRs focus on the solids generated at the facility. However, biosolids treatment and disposal regulations can be included in the NPDES permit for the treatment plant or can be covered under separate WDRs that are also issued by the RWQCB.

NPDES Pretreatment Program for Industrial Discharges.
Pretreatment of industrial discharges is mandated by the Clean Water Act of 1977 (33 USC Sections 1251-1376; P.L. No. 95-217, 91 Stat. 1566). EPA has established pretreatment standards (see 40 CFR Part 403) for various industrial categories. EPA created the National Pretreatment Program and first issued pretreatment regulations in November 1973. Following amendment of the Clean Water Act, the regulations were

revised in June 1978 and again in January 1981. The purpose of the National Pretreatment Program is to regulate the discharge of toxic pollutants or unusually large amounts of conventional pollutants (e.g., BOD and total suspended solids [TSS]) to municipal sanitary sewers and the associated wastewater treatment plants. Toxic pollutants can include a large variety of potential compounds but generally refer to the EPA priority pollutant trace metal and organic compounds, other volatile organic compounds and SVOCs, pesticides, and chlorinated organic compounds. The goal is to protect receiving water quality and the environment from the effects of these discharges because of their potential to "pass through" or receive only partial or no treatment by the wastewater treatment plant.

An individual pretreatment program typically consists of: (1) identification of pollutants that could cause upset or bypass (pollutants of concern); (2) development of discharge limitations for nondomestic discharges (local limits); (3) identification of nondomestic discharge sources; and (4) implementation of nondomestic monitoring program to enforce the local limits. Local limits may include both narrative and numeric limits. Narrative limits are general statements of prohibitions or restrictions of a particular discharge, while numeric local limits are maximum allowable concentrations that are calculated for each pollutant of concern that a facility discharge to the sewer cannot exceed. Numeric local limits are calculated from the most limiting criteria or standard that could upset the wastewater treatment process or pass through in the effluent. The criteria and standards used for the local limit calculations include the applicable state and federal water quality criteria described above. Local agencies develop, and seek EPA approval of, their industrial pretreatment programs through local sewer-use ordinances.

Narrative and numeric limits used in source control programs have effectively reduced the pollutant concentrations entering the facility. A fraction of the pollutants are removed from the wastewater that is treated at the facility. Because most toxic trace metal and organic compounds are not destroyed during the wastewater treatment process, most of the fraction removed from the wastewater end up in the biosolids generated at the facility. Removal rates of trace metals and organic compounds are fairly constant at treatment facilities; therefore, lower influent pollutant concentrations results in lower biosolids pollutant concentrations. Source control programs have significantly reduced the biosolids pollutant concentrations. This is shown by the decrease in biosolids pollutant concentration at facilities with aggressive source control programs. As source control programs are continually being improved because of more stringent pollutant limitations, pollutant concentrations in biosolids will continue to decrease or, at a minimum, remain the same in the future.

Nonpoint Source Assessment and Watershed Initiative

In 1988 the SWRCB prepared the "Nonpoint Source Assessment Report" (California State Water Resources Control Board 1988) documenting water quality threats from these sources and evaluating programs designed to reduce this contaminant threat.

Nutrients, sedimentation, and other agriculture chemicals are acknowledge as having contributed to groundwater and surface water impairment. Unlike point sources of contamination which are discreet and subject to regulatory control, nonpoint sources (NPS) of contamination are typically associated with long standing and generally acceptable societal practices and land use activities where liability for contamination is hard to determine, and where regulatory programs cannot easily remedy the problem. Agriculture, silviculture, urban stormwater runoff and grazing are examples of land uses activities that have the potential to degrade water quality. The SWRCB has begun to define strategies to deal with NPS contamination and is developing a watershed management initiative (California State Water Resources Control Board 1995a), which focuses on voluntary measures and cooperative programs to reduce potential water quality threats.

Agricultural operations in California are as diverse as the geography. A wide variety of crops are grown under diverse soils, irrigation, and climatic conditions, making it difficult to prescribe globally applicable management practices which are appropriate for every conditions. The SWRCB recognizes that individually prescribed management practices should be specific to the unique crops, soils, and the potential risks to groundwater (California State Water Resources Control Board 1994). The Technical Advisory Committee for Plant and Nutrient Management was convened to assist in developing the "Initiatives in Nonpoint Source Management" (California State Water Resources Control Board 1995b), prepared to respond to nonpoint-source contamination in California. Technical Advisory Committee for Plant and Nutrient Management recommended that specific assessments of farming activities be conducted by agricultural experts familiar with unique agronomic conditions and local practices. It was anticipated that these assessments would be used to define appropriate best management practices (BMPs) to control nutrient leaching and to apply best available information and current research. Many of the concepts and programs contained in the watershed management program have been included in the GO and will serve to reduce the potentially significant impact to less then significant.

Nitrate Management: Research, Technical Support and Technology Transfer on Agronomic Rates

DFA's FREP program was created to advance the environmentally safe and agronomically sound use and handling of fertilizer materials. The program facilitates and coordinates the development of applied research and demonstration projects providing technical assistance and funding to carry out research, demonstration and education projects related to use of nitrogen fertilizers in agriculture. FREP also seeks to improve access to information on agronomic uses of nitrogen and to serve as a clearing house for data and research. Funding is provided by a tax on agricultural fertilizers. FREP is part of the Nitrate Management Program established by DFA in 1990 to identify nitrate sensitive areas and to reduce agriculture's contribution to nonpoint sources of nitrate contamination. The information and research generated and distributed by FREP will assist in defining nitrogen agronomic rates for a range of crops and conditions found in California and to ensure compliance with prohibitions specified in the GO.

The Certified Crop Adviser (CCA) program has been developed by the American Society of Agronomy (ASA) in cooperation with agribusiness retail dealers, cooperatives and manufacturers, state and national trade associations, the U.S. Department of Agriculture (USDA), and independent consultants. The aim of this group was to develop a voluntary program for crop advisers that would: establish standards for knowledge, experience, ethical conduct and continuing education; enhance professionalism; and promote dialogue among those involved in agriculture and natural resource management. The CCA program is coordinated by the American Society of Agronomy and administered at the local level by state or regional boards. To become a Certified Crop Adviser, a person must have up to 4 years of crop advising experience, depending on educational background; document their education and crop advising experience with supporting references and transcripts; and pass comprehensive national and state/regional/provincial examinations that evaluate knowledge in four competency areas (soil fertility, soil and water management, integrated pest management, and crop management). CCAs can assist in determining agronomic rates for biosolids application to reduce the potential for nitrate leaching and groundwater contamination.

The University of California, California State University, local County Agricultural Extension Service offices, the U.S. Natural Resources Conservation Service, and USDA are all actively pursuing projects and research related to nutrient management and agronomic rates of nitrogen for various crop conditions in California. This information is being made widely available through local resource conservation districts, water districts, agricultural organizations and county agricultural commissioners. These same groups have been conducting research and demonstration projects to evaluate the effectiveness of on-farm BMPs for reducing nitrate contamination.

Drinking Water Source Water Assessment and Protection Program

The California DHS Division of Drinking Water and Environmental Management is developing a program to assess the vulnerability of drinking water sources to contamination (California Department of Health Services 1999). This program, which is required by federal and state law, is called the Drinking Water Source Water Assessment and Protection (DWSAP) Program. DHS submitted its DWSAP Program Document to the EPA on January 19, 1999. The wellhead protection portion of the program has been approved by the EPA, and DHS anticipates receiving approval of the surface water component in mid-1999. Completion of drinking water source assessments is required by April 2003. The federal Safe Drinking Water Act (SDWA) requires states to develop a program to assess sources of drinking water and establish protection programs.

California's DWSAP Program is the first step in the development of a complete drinking water source protection program, and will include evaluation of both ground water and surface water sources. The groundwater DWSAP program includes components intended to fulfill the requirements for state development of a Wellhead Protection Program strategy as required by Section 1428 of the Safe Drinking Water Act Amendments of 1986. The purpose of the program is to protect ground water sources of public drinking water supplies from contamination, thereby eliminating the need for costly treatment to meet drinking water standards. The program is based on the concept that the development and application of land-use controls (usually applied at the local level in California) and other preventative measures can protect ground water. A Wellhead Protection Area (WHPA), as defined by the 1986 Amendments, is "the surface and subsurface area surrounding a water well or wellfield supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield". The WHPA may also be the recharge area that provides the water to a well or wellfield. The DHS's assessment includes a delineation of the area around a drinking water source through which contaminants might move and reach that drinking water supply. DHS must inventory possible contaminating activities (PCAs) that might lead to the release of microbiological or chemical contaminants within the delineated area. This enables a determination to be made as to whether the drinking water source might be vulnerable to contamination. DHS is to conduct the surveys but local agencies may undertake the assessment.

An essential element of the drinking water source assessment program is an inventory of PCAs that are considered to be potential sources of contamination in the designated drinking water source areas and protection zones. Irrigated agriculture and land application of biosolids are recognized as PCAs. As such specific set back requirements from municipal and domestic wells and from surface water sources that provide drinking water will be required upon completion of the assessments and vulnerability analysis by DHS or locally responsible agencies. Biosolids application, along with agricultural applications of fertilizer, are classified as having a moderate potential risk of contaminating drinking water (California Department of Health Services 1999).

Groundwater Management Plan (AB 3030)

Sections 10750-10756 of the California Water Code (AB 3030) were signed into law in 1992 and describes components that may be included in a ground water management plan developed by a local agency to protect groundwater. A total of 149 agencies have adopted groundwater management plans in accordance with AB 3030 (California Department of Water Resources 1994c). Each component would play some role in evaluating or operating a ground water basin so that ground water can be managed to maximize the total water supply while protecting ground water quality. Department of Water Resources Bulletin 118-80 defines groundwater basin management as including planned use of the ground water basin yield, storage space, transmission capability, and water in storage (California Department of Water Resources 1975). Ground water basin management includes the following elements:

- protection of natural recharge and use of intentional recharge,
- planned variation in amount and location of pumping over time,
- use of ground water storage conjunctively with surface water from local and imported sources, and
- protection and planned maintenance of ground water quality.

The 12 components listed in Section 10753.7 of the Ground Water Management Act (AB 3030) form a basic list of data collection and operation of facilities that may be undertaken by an agency operating under this act. With respect to protecting groundwater from potential contamination from biosolids, the critical components to be included in local plans include the following:

- identification and management of wellhead protection areas and recharge areas;
- regulation of the migration of contaminated groundwater;
- administration of a well abandonment and well destruction program;
- monitoring of groundwater levels and storage;
- review of land use plans and coordination with land use planning agencies to assess activities that create a reasonable risk of groundwater contamination.

Citations

Alexander, M. 1995. How toxic are toxic chemicals in soil? Environmental Science and Technology 29(11):2713-2717.

Breuggeman, A.C. and S. Mostaghimi. 1993. Sludge application effects on runoff, infiltration, and water quality. Water Resources Bulletin 29(1):15-26.

California Data Exchange Center. 1999. Internet database of real-time water supply monitoring data. URL: cdec.water.ca.gov

California Department of Food and Agriculture. 1989. Nitrates and Agriculture in California. February 1989. Sacramento, CA.

California Department of Food and Agriculture. 1998. Fertilizer Research and Education Internet home page: URL:www.cdfa.ca.gov/inspection/frep/docs/about_frep.html

California Department of Health Services. 1999. Drinking Water Source Assessment and Protection Program. Division of Drinking Water. January 1999. Sacramento, CA.

California Department of Water Resources. 1975. Bulletin 118-75. California's Ground Water. California State Resources Agency. Sacramento, CA.

California Department of Water Resources. 1994a. Bulletin 160-93. California Water Plan Update. Sacramento, CA.

California Department of Water Resources. 1994b. Five-year report of the Municipal Water Quality Investigations Program. Division of Local Assistance. Sacramento, CA.

California Department of Water Resources. 1999. Internet database of archived water quality monitoring data in the San Joaquin - Sacramento River Delta. URL: wwwdla.water.ca.gov/cd/delmon/

California Irrigation Management Information System. 1999. Internet database of real-time atmospheric and precipitation monitoring data. URL: wwwdla.water.ca.gov/cgi-bin/cimis/hg/main.pl

California Regional Water Quality Control Board. 1994. Water quality control plan. Central Coast. Sacramento, CA.

California Regional Water Quality Control Boards. 1995. Regional Water Quality Control Plans (1995). State Water Resources Control Board. Sacramento, CA.

California State Water Resources Control Board. 1988. Nitrates in Drinking Water, Report to the Legislature. Report No. 88-11WQ. Division of Water Quality. October 1988. Sacramento, CA.

California State Water Resources Control Board. 1994. Report of the Technical Advisory Committee for Plan Nutrient Management. November 1994. Sacramento, CA.

California State Water Resources Control Board. 1995a. Nonpoint Source Assessment. Sacramento, CA.

California State Water Resources Control Board. 1995b. Initiatives in Nonpoint Source Management. Sacramento, CA.

California State Water Resources Control Board. 1996. Water Quality Assessment Report. California State Resources Agency. Sacramento, CA.

California Teale Data Center. 1999. Internet database of archived GIS data. URL: www.teale.ca.gov

Camobreco, V.J., B.K. Richards, T.S. Steenhuis, J.H. Peverly, and M.B. McBride. 1996. Movement of heavy metals through undisturbed and homogenized soil columns. Soil Science 161(11):740-750.

Chaney, R.L. 1990. Twenty years of land application research. Biocycle September 1990: 54-59.

Clapp, C.E., W.E. Larson, and R.H. Dowdy. 1994. Sewage Sludge: Land Utilization and the Environment. In O'Connor, G.A. Sewage sludge: toxic organic considerations. pp. 33-34. Published by American Society of Agronomy Inc., Crop Science Society of America Inc., and Soil Science Society of America Inc., Madison, WI.

Colwell, W.L. 1979. Forest soils of California. *In* California Forest Soils: a guide for professional foresters and resource managers and planners. Division of Agricultural Sciences, University of California.

Cornell Waste Management Institute. 1999. The case for caution: recommendations for land application of sewage sludges and an appraisal of the U.S. EPA's Part 503 sludge rules. Working Paper August 1997; revised February 1999. Prepared by E.Z. Harrison, M.B. McBride, and D.R. Bouldin. Center for the Environment, Cornell University, Ithaca, NY.

Demirjian, Y.A., A.M. Moshi, and T.R. Westman. 1987. Fate and organic compounds in land application of contaminated municipal sludge. Journal Water Pollution Control Federation 59(1): 32-38

Donahue, R.L., R.W. Miller, and J.C. Shickluna. 1983. Soils: An introduction to soils and plant growth. Fifth Edition. Prentice-Hall, Inc. Englewood Cliffs, N.J.

Dowdy, R.H., J.J. Latterell, T.D. Hinesley, R.B. Grossman, and D.L. Sullivan. 1991. Trace metal movement in an aeric Ochraqualf following 14 years of annual sludge applications. J. of Environmental Quality 20:119-123.

EarthInfo Inc. 1994. Environmental Protection Agency STORET database information for California Department of Water Resources Surface Water Data. Boulder, CO.

Emmerlich, W.E., L.J. Lund, A.L. Page, and A.C. Chang. 1982. Movement of heavy metals in sewage sludge treated soils: solid phase forms of heavy metals in sewage sludge-treated soils - predicted solution phase forms of heavy metals in sewage sludge-treated soils. J. Environmental Quality 11:174-186.

Holmgren, G.G.S., M.W. Meyer, R.L. Chaney, and R.B. Daniels. 1993. Cadmium, lead, zinc, copper, and nickel in agricultural soils of the United States of America. Journal of Environmental Quality 22:335-348.

Krogman, U., L.S. Boyles, C.J. Martel, and K.A. McComas. 1997. Biosolids and sludge management. Water Environment Research. 69: 534-550.

Letey, J., C. Roberts, M. Penberth, and C. Vasek. 1986. An agricultural dilemma: drainage water and toxics disposal in the San Joaquin Valley. Contribution of the University of California Kearney Foundation of Soil Science 1980-1985 mission on "Soil and Plant Interactions with Salinity." Riverside, CA.

McGrath, S.P., and P.W. Lane. 1989. An explanation for the apparent losses of metals in a long-term field experiment with sewage sludge. Environmental Pollution 60:235-256.

Mostaghimi, S., T.M. Younos, and V.S. Tim. 1992. Effects of sludge and chemical fertilizer application on runoff water quality. Water Resources Bulletin 28(5):545-552

Mount, Jeffrey F. 1995. California Rivers and Streams. University of California Press. Berkeley, CA.

National Academy of Sciences. 1996. Use of Reclaimed Water and Sludge in Food Crop Production. Committee on the Use of Treated Municipal Wastewater Effluents and Sludge in the Production of Crops for Human Consumption, Water Science and Technology Board, Commission on Geosciences, Environment and Resources, National Research Council. National Academy Press, Alexandria, VA .

Northwest Biosolids Management Association. 1998. Literature Review on Runoff Water Quality from Biosolids Applications. Grey, M, Henry C., Thompson, D. University of Washington College of Forest Resources. Seattle, WA.

Pacific Gas and Electric Company. 1989. Generalized soil map of California. (Adapted from a map by R.E. Storie and W.W. Weir, Division of Agriculture and Natural Resources, University of California, Berkeley, 1951.) San Francisco, CA.

Phung, T, L. Barker, D. Ross, and D. Bauer. 1978. Land cultivation of industrial wastes and municipal solid wastes: state-of-the-art study, Volume I, Technical Summary and Literature Review. SCS Engineers. EPA-600/2-78-140a. Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. Cincinnati, OH.

Rappe, C., R. Andersson, C. Nilsson, and P. Nilsson. 1997. A field study on the use of sewage sludge as soil amendment. Organohalogen Compounds 32: 45-50

Reed, S.C. and R.W. Crites. 1984. Handbook of land treatment systems for industrial and municipal wastes. Noyes Publications, Park Ridge, NJ.

San Joaquin Valley Drainage Program. 1990. A management plan for agricultural subsurface drainage and related problems on the westside San Joaquin Valley. Final Report. U.S. Department of the Interior Bureau of Reclamation, Fish and Wildlife Service, and Geological Survey, and California Resources Agency Department of Fish and Game and Department of Water Resources. Sacramento, CA.

Sidle, R.C., and L.T. Kardos. 1977. Transport of heavy metals in a sludge-treated forested area. J. of Environmental Quality 6:431-437.

Sommers, L.E., D.W. Nelson, R.E. Terry, and D.J. Silviera. 1976. Nitrogen and metal contamination of natural waters from sewage sludge disposal on land. Technical Report No. 98. Purdue University Water Resources Research Center. West Lafayette, IN.

Tidball, R.R., R.C. Severson, J.M.. McNeal, and S.A. Wilson. 1986. Distribution of selenium, mercury, and other elements in soils of San Joaquin Valley and parts of the San Luis Drain Service area, California. *In* Selenium and Agricultural Drainage: Implications for San Francisco Bay and the California Environment, Proceedings of the Third Selenium Symposium, March 15, 1986, Berkeley, CA.

Tindall, J.A., K.J. Lull, and N.G. Gaggiani. 1994. Effects of land disposal of municipal sewage sludge on fate of nitrates in soil, streambed sediment, and water quality. Hydrobiologia 163:147-185.

Tucker, G.B., W.A. Berg, and D.H. Gentz. 1987. pH. *In* Reclaiming mine soils and overburden in the western United States - analytic parameters and procedures. R. D. Williams and W.E. Schuman, eds. Soil Conservation Society of America, Ankeny, IA.

U.S. Department of Agriculture. 1993. Soil survey manual. U.S. Department of Agriculture Handbook 18. U.S. GPO, Washington, D.C.

U.S. Environmental Protection Agency. 1990. Technical support documentation for Part 1 of the National Sewage Sludge Survey Notice of Availability. Analysis and Evaluation Division. October 31, 1980. Washington, D.C.

U.S. Environmental Protection Agency. 1992. Technical support document for land application of sewage sludge. Volume 1. Prepared for Office of Water by Eastern Research Group, Lexington, MA. November 1992. Washington, D.C.

U.S. Environmental Protection Agency. 1995. A guide to the biosolids risk assessments for the EPA Part 503 rule. EPA832-B-93-005. Office of Wastewater Management. September 1995. Washington, D.C.

U.S. Environmental Protection Agency. 1999. Internet access to STORET database of archived water quality data. URL: www.epa.gov/owow/storet

U.S. Geological Survey. 1999a. Internet database of archived streamflow records for California rivers. URL: water.wr.usgs.gov/sites/

U.S. Geological Survey. 1999b. Internet database of archived water quality data. URL: wwwrvares.er.usgs.gov/wqn96cd

U.S. Soil Conservation Service. 1981. Major land resource regions and major land resource areas of the United States. Agricultural Handbook 296. U.S. Department of Agriculture.

University of California. 1995. Department of Land, Air, and Water. Fogg, G., Rolston, D., LaBolle, E., Burow, K., Maserjian, L., Decker, D., Carle, S. Matrix Diffusion and Contaminant Transport in Granular Geologic Materials with Case Study of Nitrate Contamination in Salinas Valley, California. Davis, CA.

University of Washington. 1991. Literature Reviews on Environmental Effects of Sludge Management. Prepared for Regional Sludge Management Committee. Prepared by College of Forest Resources. Edited by C.L. Henry and R.B. Harrison. July 1991. Sacramento, CA.

Wallace, A. and G.A Wallace. 1994. A possible flaw in EPA’s 1993 new sludge rule due to heavy metal interactions. Community Soil Science Plant Analysis 25(1&2):129-135.

Water Environment Federation. 1994. Beneficial use programs for biosolids management. Alexandria, VA.